Determination of the Temperature Coefficient, and Coefficient of Resistivity Of Copper, Iron and Aluminum

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DETERMINATION OF THE TEMPERATURE

COEFFICIENT, AND COEFFICIENT OF RESISTIVITY

OF COPPER, IRON AND ALUMINUM

A THESIS

PRESENTED BY

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BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

ELECTRICAL ENGINEERING

John E. Snow
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Dean of Engineering Studies

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Dean of Cultural Studies.

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DETERMINATION OF TEMPERATURE COEFFICIENT AND COEFFICIENT OF RESISTIVITY OF COPPER, IRON, AND ALUMINIUM.

The object of the following experiments was to find the mean temperature coefficient, α, between the temperatures of 0° and 100° Centigrade, in the formula

$$R_t = R_o(1 + \alpha t)$$

in which R_o is the resistance of a conductor at 0° C. and R_t at t° C.; also the mil-foot resistance, and the volume and mass resistivity of various samples of copper, iron and aluminium.

The temperature coefficient, α, is defined to be the increase in resistance of a conductor per degree per ohm resistance at 0° C. The mil-foot resistance of a conductor is the resistance of a conductor one foot long and one circular mil in cross sectional area. The volume resistivity of any material is defined to be the resistance of a cube of the material one centimeter on a side. The usual manner of stating this resistivity is in michroms per centimeter cube at 0° C. To determine the volume resistivity of a sample of a metal or alloy, it is desirable tp possess it in the form of a carefully drawn wire of uniform circular cross section. Owing to the difficulty of determining the diameter of very fine wires, it is found more desirable and convenient to determine and define the resistivity of metals and alloys by the resistance in ohms per meter gramme at 0° C., that is to say, by stating the ohmic resistance at 0° C. of a wire of circular cross section having a length of one meter and weighing one gramme.

This is known as the mass resistivity.

The samples tested were copper, steel and aluminium wires as follows:

Sample 1. #10 B.&S. gauge, annealed copper wire obtained from John A. Roebling's Sons Co.

Sample 3. #14 B.& S. gauge annealed copper wire.

Sample 4. #14 B.& S gauge annealed copper wire.

Sample 5. #14 B.& S. gauge annealed copper wire.

Sample 6. #14 B.& S. gauge annealed copper wire.

Sample 0. # 8 B.& S. gauge annealed copper wire, obtained from the Okanite Co.

Sample 10. # 9 B.& S. gauge annealed copper wire, obtained from the American Steel & Wire Co.

Sample 2. # 8 B.W.G. steel wire, American Steel & Wire Co's Extra B.B.

Sample 7. Roebling's #8 B.B.

Sample 8. Roebling's #8 Extra B.B.

The three samples of steel were obtained through the courtesy of the Ristine Co.

Samples I and II of annealed Aluminium about #10 B.W.G. from the American Aluminium Co.

The resistances at various temperatures ranging from 0° to 100° C. were measured by means of the Thompson double bridge. A scheme of the bridge and the connections for the determination of the resistances is shown on an accompanying blue print. The principle of the bridge method is that of balancing the drop across the unknown resistance against the drop across a

known resistance, so that all the resistances of lead wires are eliminated. The wire to be tested was cut into samples twenty-two inches in length and a sample was placed in the box containing the oil bath for heating and fastened and held straight by means of the clamps, AA, (see photograph) which are connected to the series posts of the box. The wire was then connected in series with the known resistance, a Hartmann and Braun .001 ohm standard manganin resistance, and also in series with an ammeter, a carbon rheostat, a storage cell and a switch as shown in the scheme. The rheostat was adjusted so that a current of 15 amperes flowed through the series circuit. The heating box is so arranged that the knife edges, exactly 50 centimeters apart, rest upon the wire to be tested, between the series posts, so that the drop across 50 centimeters of the wire is balanced against the drop across the standard resistance. These knives, BB ,in the photograph, are connected by large copper leads to the pressure binding posts on the top of the box. These posts were connected to the posts marked, xx , on the bridge and also the pressure posts on the standard resistance were connected to the posts marked, NN , on the bridge. The galvanometer was also connected as shown in the scheme. The galvanometer used was a Leeds and Northrop, suspended coil type, mounted in a wall case on springs so that the jarring of the building would have a minimum effect in deflecting the coil. The deflection was read by means of a telescope and scale so as to obtain a maximum accuracy in the adjustment of the resistances

on the bridge for a balance, the coil showing no deflection at this point.

To obtain temperatures above that of the room, the oil bath surrounding the wire was heated by an electric heating coil. Readings of resistance were taken about every five degree increments in temperature up to 100° C., the oil being constantly stirred both by hand and electric motor. At each temperature where the resistance was measured the heat was partly shut off, only enough being left on to keep the temperature constant, the amount of heating current left on being adjusted through a lamp rack. After the temperature had remained constant for a short time, the dials on the bridge were adjusted, the two 100 plugs, as shown in the photograph being out, until the galvanometer showed no deflection; the temperatures and resistances were then read simultaneously and recorded.

The temperatures below that of the room were obtained by running cold brine through a coil of tin piping in the oil bath. The arrangement for running the brine through the coil from a tank is shown in a photograph of the apparatus. On account of the high congealing point of the oil used for the high temperatures, kerosene was substituted for the low temperatures. In this way the temperature of the bath was reduced to 0° C., readings of resistance being taken as before.

The temperatures were read by means of two accurate thermometers, reading from 0° to 100° C., and graduated to tenths of a degree, placed in the oil through the top of the heating

box. The mean temperature of the wire for each reading was taken as the average between the two thermometer readings. This mean temperature was corrected for the mercury in the stem projecting above the oil in the box by means of the formula

$$T = t - .000143\, n\, (t' - t) \qquad \text{(Smithsonian Tables)}$$

in which T is the corrected temperature, t, the observed temperature, and t', the mean temperature of glass stem and mercury column; this temperature was assumed to be a little above room temperature; n is the length of the mercury column in the stem in scale degrees, this length being figured from the fifteen degree point, the mercury being subjected to the heat of the oil up to the fifteen degree mark. This correction amounts to about nine tenths of a degree at 100° C.

According to the certificate for the Hartmann and Braun standard resistance as tested by the Bureau of Standards, ~~is~~ its resistance at 20.4° C. is .00099846 international ohms. This value was used throughout as the resistance of the standard coil. If N is the reading on the dials of the bridge for a balance, then R, the resistance of fifty centimeters of the wire, is given by the equation

$$\frac{R}{.00099846} = \frac{N}{100} \quad \text{or} \quad R = N \times \frac{.00099846}{100}$$

when the two 100 plugs are out.

Curves were platted as shown on sheets 1 to 12 with temperature as abscissae and resistances as ordinates. From these curves, which were found to be straight lines, the everage temperature coefficient was obtained. The mean temperature coefficient was taken as the average coefficient figured from each of the pointswhich fell on the curves.

The mil-foot resistance for each sample was found at 0° C. and at one or two other temperatures at which the resistance fell on the resistance-temperature curve. From these points straight line curves were drawn which show the relation of mil-foot resistance to temperature. In the same way straight line curves were drawn which show the relation of the mass and volume resistivity to temperature. The mil-foot temperature-resistance curves are shown on sheets 13 to 22 and those for the mass and volume resistivity on sheets 23 to 32.

The mass rsistivity in ohms per meter gramme at 0° C. was found from the formula

$$\rho' = \frac{10^4 \; M \; R}{l^2}$$

in which ρ' = mass resistivity, M = mass ~~resistivity~~ of fifty centimeters of sample in grammes, R = resistance of sample in ohms at 0° C. and l = the length of the wire in centimeters.

The volume resistivity in michroohms per cubic centimeter at 0° C. was found from the formula

$$\rho = \frac{\rho' \times 10^2}{d}$$

where ρ is the volume resistivity at 0° C. and d is the density.

The density, d , of each sample was found by weighing it in and out of distilled water by means of an accurate chemical balance.

The diameters of the samples were found by means of micrometer calipers. Measurements were taken at several points along the wire, twice at each point, one reading being taken when the micrometer caliper was at right angles to the position when the first reading was taken. The diameter was

then taken as the average of all the readings.

In order to find out whether the samples of copper were hard drawn or annealed tests were made to find the tensile strength.

Data were secured as to the chemical composition and purity of all the copper samples except sample 1 as follows:

Sample	% Copper	% Tin
3	99.49	.3
4	99.	.47
5	99.18	.29
6	99.1	.32
0	98.41	.31
10	99.64	.28

In the above samples the tin appeared only as a coating which would not affect the value of the temperature coefficient or resistivity, the per cent being so small. Sample 1 had no such tin coating.

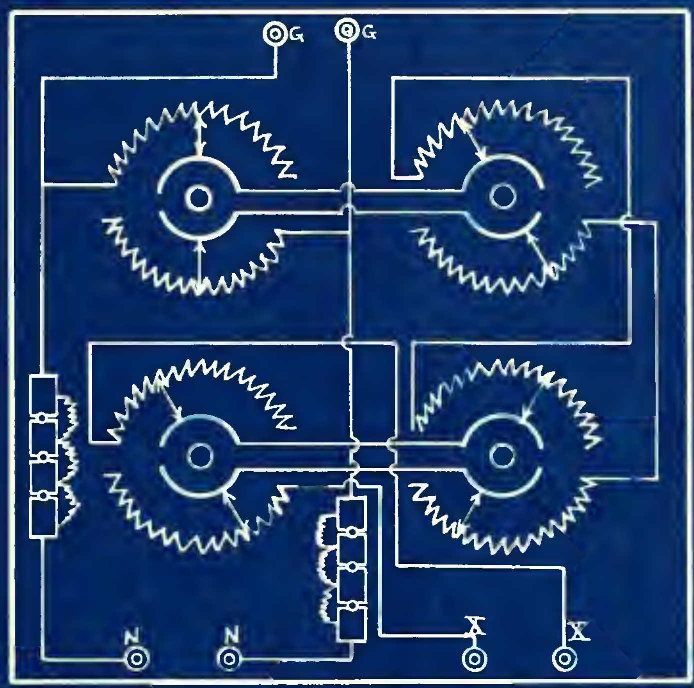
The average temperature coefficient for all the copper samples is .004221, ~~and~~ the maximum value being .004288 and the minimum, .004123. Any slight difference in the purity or treatment of copper will affect its temperature coefficient. The value for the temperature coefficient adopted in the A.I.E.E. Standerdization Rules is .0042; the German rules adpot .004, while on the other hand the British Engineering Standards Committee use .00428. The value of the coefficient, .004221, corresponds very nearly to that of the A.I.E.E. Standardization Rules.

The variation of the temperature coefficient for the steel

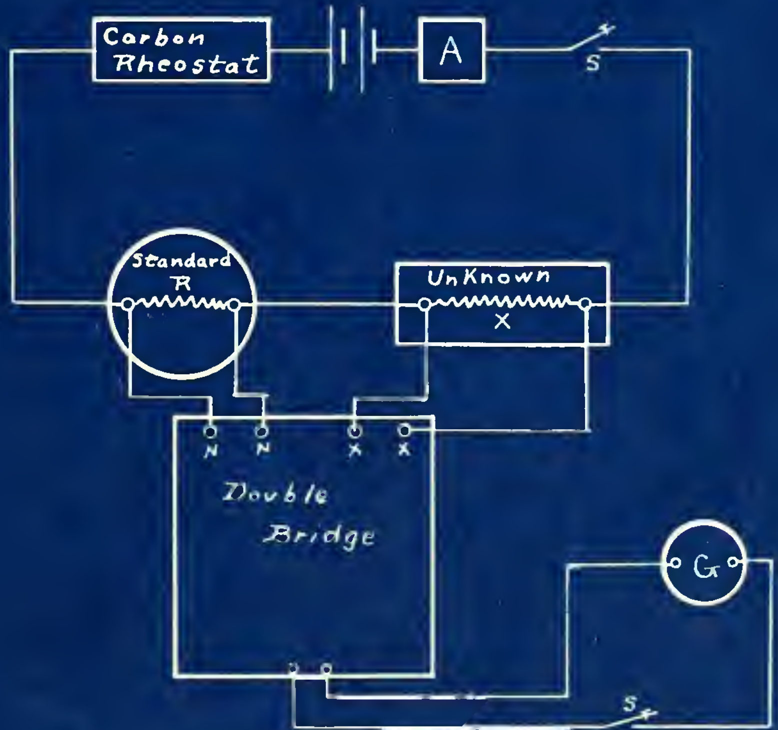
wire is probably due to the different chemical composition and treatment of the samples; however no data as to their purity were obtainable.

The average value of the temperature coefficient, .004455, for aluminium seems to be rather high compared to the value .00435 obtained by Dewar and Fleming for annealed aluminium. Since the purer the metal the greater the temperature coefficient, this would indicate that the sample tested was fairly pure, probably about 99.75% or 99.8% pure. It is also the case that the purer the metal the less the resistivity. It has been determined that the volume rsistivity at 0° C. in michrohms per cubic centimeter for annealed aluminium, 99.66% pure is 2.4322. Since the value obtained here, i.e. 2.421, is lower, this would seem to verify the above estimate as to the ~~the~~ purity of the sample of aluminium tested.

Scheme of Connections of Thompson Double Bridge



Scheme of Connections for Test.



Sample I Aluminium Wire.

#10 B.W.G.

Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
0.0	.001321	51.51	..001623
5.4	.0013455	56.15	.001650
10.5	.0013755	62.22	.0016865
17.83	.0014255	66.18	.001705
20.93	.001445	70.82	.0017335
26.21	.0014655	76.43	.001766
30.85	.0015030	80.06	.0017905
40.77	.001560	86.00	.001823
46.26	.0015925	91.92	.001856
		96.64	.001883
		101.32	.0019255

Diameter .13808"

Sample II Aluminium wire.

#10 B.W.G.

Temperature C°	Resistance of 50 cm
0.0	.0013185
5.6	.001349
10.3	.0013775
14.7	.0014025
20.35	.001435
25.71	.001467
30.72	.0014995
35.99	.0015315
41.71	.001567
45.44	.0015865
50.40	.0016165

Diameter .13808 inches.

Sample 1 Annealed Copper Wire.

#10 B & S Gauge.

Temperature C°	Resistance of 50 cm.	Temperature C°	Resistance of 50 cm
0.0	.001528	50.14	.001840
17.08	.001626	54.24	.001867
19.	.001639	58.18	.001892
20.02	.001645	62.24	.001919
21.07	.001651	66.34	.001935
22.06	.001661	70.18	.001967
24.10	.001673	74.24	.001986
25.00	.001679	75.17	.001991
28.31	.001700	78.91	.002027
30.00	.001712	82.87	.002055
34.10	.001738	86.75	.002079
38.06	.001765	90.75	.002104
42.18	.001789	95.84	.002136
46.21	.001815	100.85	.002168

Diameter .10175 inches.

Sample 3 Annealed Copper Wire.

#14 B & S Guage.

Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
0.0	.003928	46.50	.004716
8.55	.004052	49.79	.004759
18.4	.0042435	60.65	.004953
19.74	.004230	64.50	.005015
20.035	.004249	70.77	.005119
26.24	.004355	75.57	.005202
30.105	.004446	80.69	.005290
34.41	.00 4514	91.52	.005469
39.97	.004577	100.65	.005620

Diameter .063495 inches

Sample 4 Annealed Copper Wire.

B&S Gauge.

Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
0.0	.003780	55.64	.004668
9.15	.003910	60.95	.004747
20.05	.004096	64.59	.004800
25.76	.004169	70.75	.004902
30.83	.004252	76.22	.004991
35.09	.004335	80.78	.005062
40.13	.004400	86.04	.005147
46.60	.004524	90.50	.005224
53.38	.004652	96.28	.005323
		100.61	.005384

Diameter .06543 inches

Sample 5 Annealed Copper Wire.

#14 B & S Gauge.

Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
0.0	.004032	56.43	.005008
10.2	.0041955	60.80	.005076
18.59	.004328	65.95	.005176
19.99	.004366	70.25	.005241
20.85	.004372	75.20	.005324
26.80	.004455	80.64	.005415
30.78	.004540	85.88	.005507
37.14	.004607	91.60	.005588
40.97	.004742	96.07	.005670
45.16	.004795	100.91	.005748
50.75	.0048865		

Diameter .06292 inches.

Sample 6 Annealed Copper Wire.

#14 B & S Gauge.

Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
0.0	.004097	45.71	.0048865
8.21	.0042035	50.55	.004984
8.99	.004252	56.76	.005087
9.5	.004251	60.71	.005118
10.19	.004255	65.61	.005210
11.61	.004281	72.35	.005346
19.99	.004413	76.34	.005420
21.06	.004433	81.18	.0054655
25.74	.004514	85.95	.005560
30.17	.004584	90.96	.005641
37.74	.004730	100.57	.005810
40.52	.004790		

Diameter .06344 inches

Sample 0 Annealed Copper Wire.

#8 B & S Gauge.

Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
0.0	.000973	56.61	.001211
10.43	.001014	61.74	.001230
17.55	.001046	65.37	.001244
23.65	.001070	71.11	.001266
27.73	.001092	76.74	.0012905
30.69	.001104	81.65	.001312
35.55	.001124	86.15	.0013[illegible]
40.72	.001143	90.93	.001350
45.97	.001165	95.77	.001370
50.2	.001185	100.59	.001387

Diameter .12726 inches.

Sample 10 Anealed Copper Wire.

#9 B & S Gauge.

Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
0.0	.0012165	51.93	..0014915
4.63	.0012395	51.90	.001491
9.59	.001265	55.04	.001509
15.09	.001295	60.62	.0015325
17.65	.0013075	65.94	.0015605
19.85	.0013205	70.16	.0015925
20.16	.001322	77.22	.0016195
25.82	.001355	81.52	.001678
32.00	.001385	85.97	.0016605
35.97	.001403	90.58	.001687
40.34	.001427	95.53	.001712
47.20	.001464	100.95	.001738

Diameter .11713 inches.

Sample 2 American Steel & Wire Co's Extra B.B. Steel Wire,

#8 B.W.G.

Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
0.0	.003428	56.62	.004546
7.875	.0035675	60.50	.004670
13.55	.003674	65.22	.004752
20.67	.003890	71.02	.004847
27.26	.004008	76.61	.0049875
30.06	.004053	81.36	.005081
36.56	.004137	86.44	.005196
40.62	.004264	91.13	.005298
46.60	.004377	95.90	.005412
51.47	.004440	100.00	.005521

Diameter .1653 inches.

Sample 7 Roebling's B.B. Steel Wire.

#8 B.W.G.

Temperature C°	Resistance of 50 cm	Temperaure C°	Resistance of 50 cm
00.0	.004486	60.48	.005751
10.49	.004691	66.97	.005861
19.34	.004899	70.36	.005957
26.18	.005066	81.38	.006188
29.91	.005133	85.96	.006296
36.04	.005263	91.71	.006424
41.31	.005334	96.32	.006535
46.35	.005431	101.37	.006639
51.08	.005554	76.10	.006059
56.88	.005660		

Diameter .1655 inches.

Sample 8 Roebling's Extra B.B.Steel Wire.

#8 B.W.G.

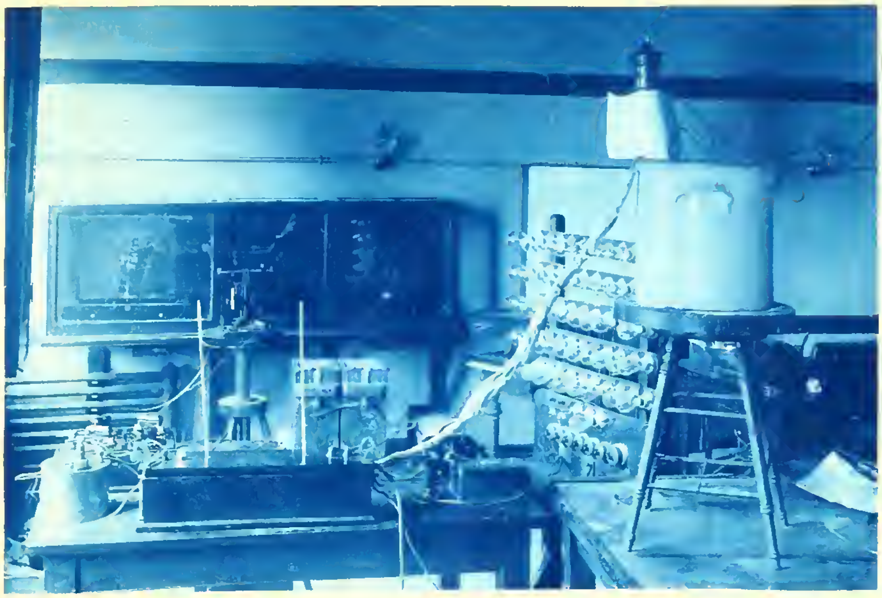
Temperature C°	Resistance of 50 cm	Temperature C°	Resistance of 50 cm
0.0	.004624	60.27	.005834
12.35	.004923	66.52	.005977
19.52	.005008	70.99	.0060835
27.56	.0052015	76.22	.006199
30.57	.005238	81.81	.006318
36.32	.005387	86.40	.006421
41.32	.005471	91.21	.006527
46.71	.005581	101.05	.006738
50.80	.005659	96.31	.006646
55.85	.005756		

Diameter .1657 inches.

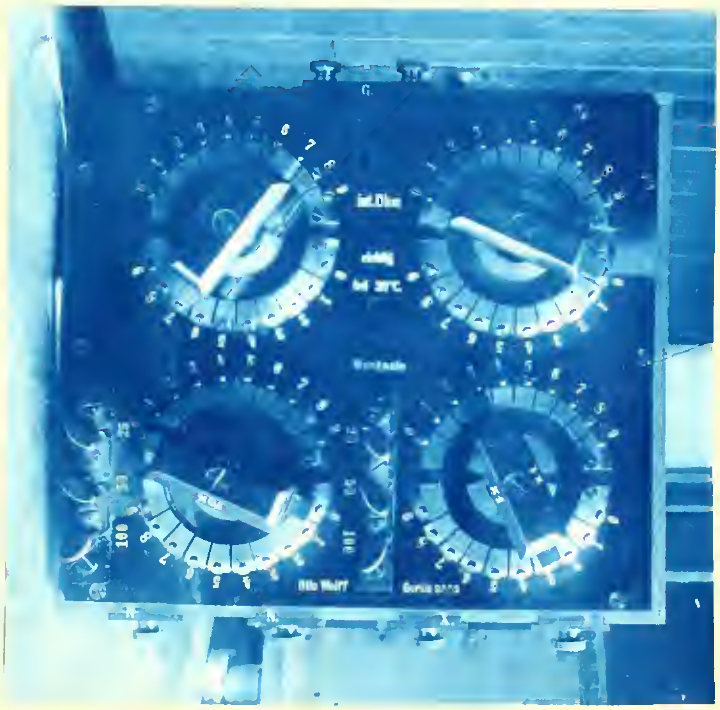
Kind of Wire.	Mean Temperature Coefficient 0–100 °C.	Mil-Foot Resistance at 0° C	Mass Resistivity ohms per Meter Gram 0°	Volume Resistivity Microhms per Cubic Cm. 0°	Density $H_2O = 1$	Breaking Load Pounds.
Sample 1. Annealed Copper.	.004238	9.618	.1436	1.592	9.0214	290.
Sample 3. Annealed Copper.	.004288	10.59	.1431	1.605	8.92	117.5
Sample 4. Annealed Copper.	.004229	9.914	.1449	1.6375	8.8468	123.7
Sample 5. Annealed Copper	.004123	9.809	.1444	1.620	8.910	117.9
Sample 6. Annealed Copper.	.004181	9.813	.1447	1.615	8.942	118.6
Sample 0. Annealed Copper.	.004258	9.669	.1419	1.596	8.891	440.
Sample 10. Annealed Copper	.004231	9.574	.1414	1.582	8.940	368.
Sample 2. Steel.	.005976	57.34	.7388	9.472	7.80	
Sample 7. Steel.	.004661	75.40	.9766	12.45	7.842	
Sample 8. Steel.	.004515	77.90	1.006	12.87	7.8184	
Sample I. Aluminum.	.004423					
Sample II. Aluminum.	.004455					
Aluminum. Average.	.004439	15.43	.06549	2.421	2.705	

Heating Box.

View of Cover of Heating Box showing
Knife Contacts.

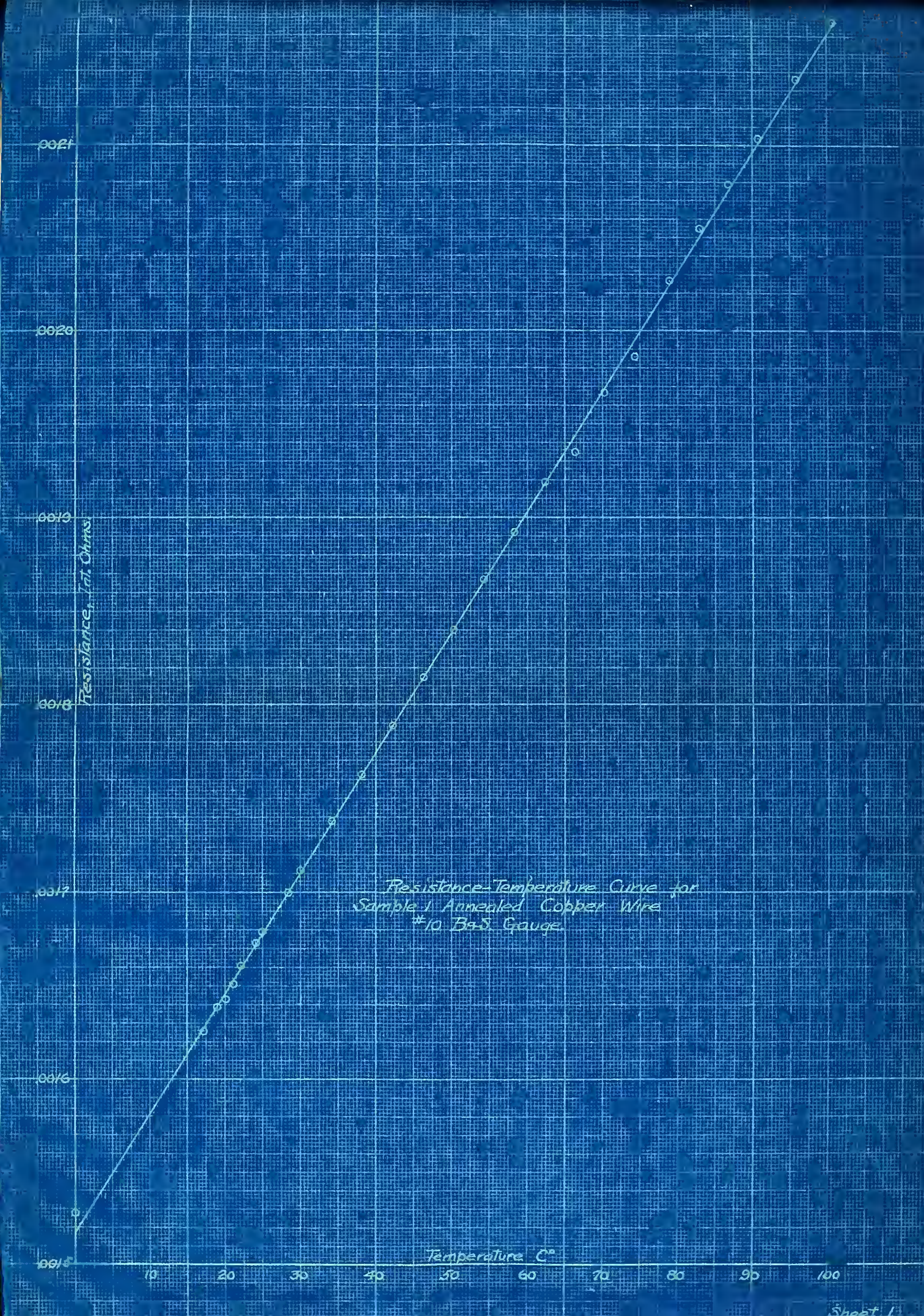


Arrangement of Apparatus.

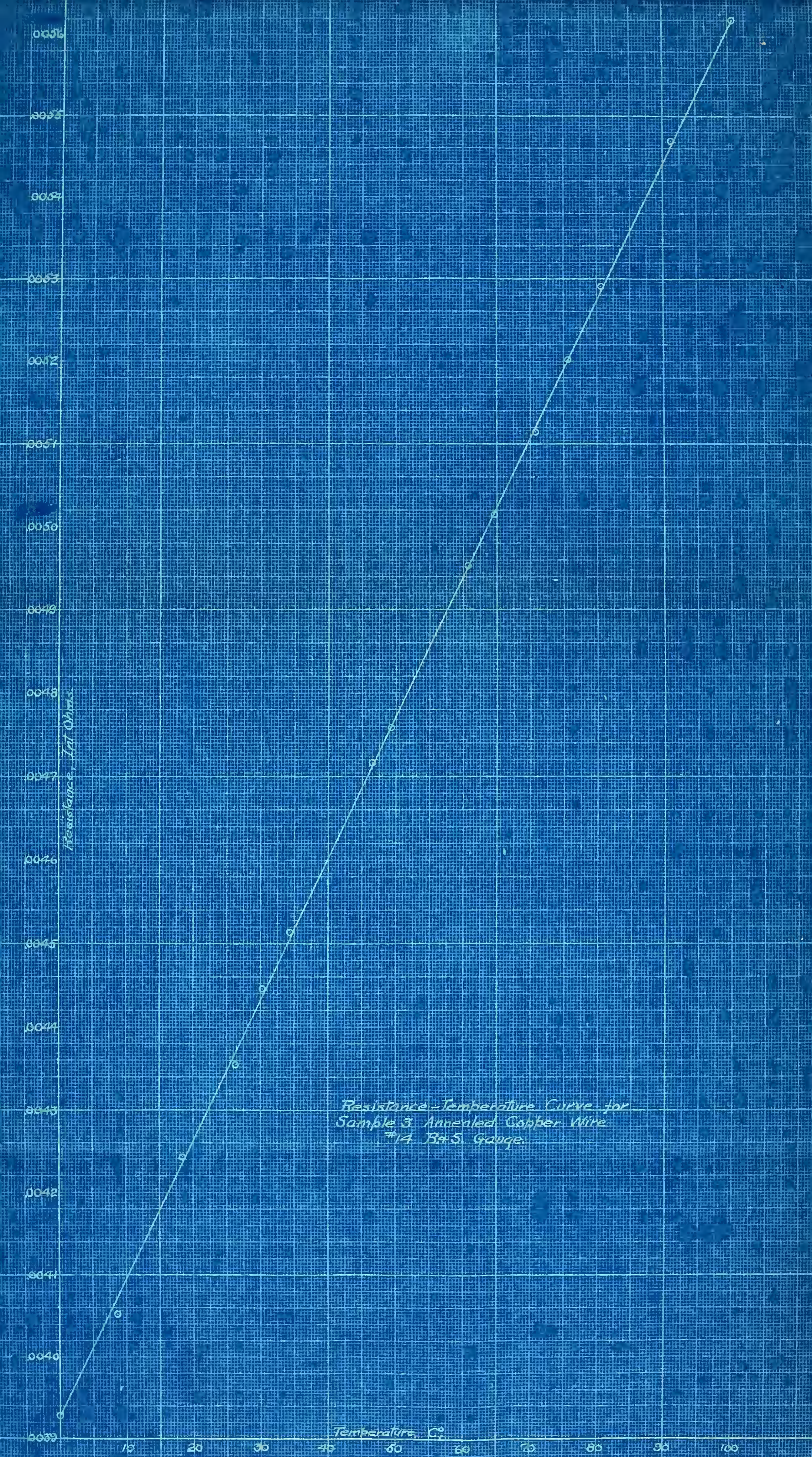


View showing Dials and Ratio
Plugs of Thomson Double Bridge.

Arrangement of Apparatus.

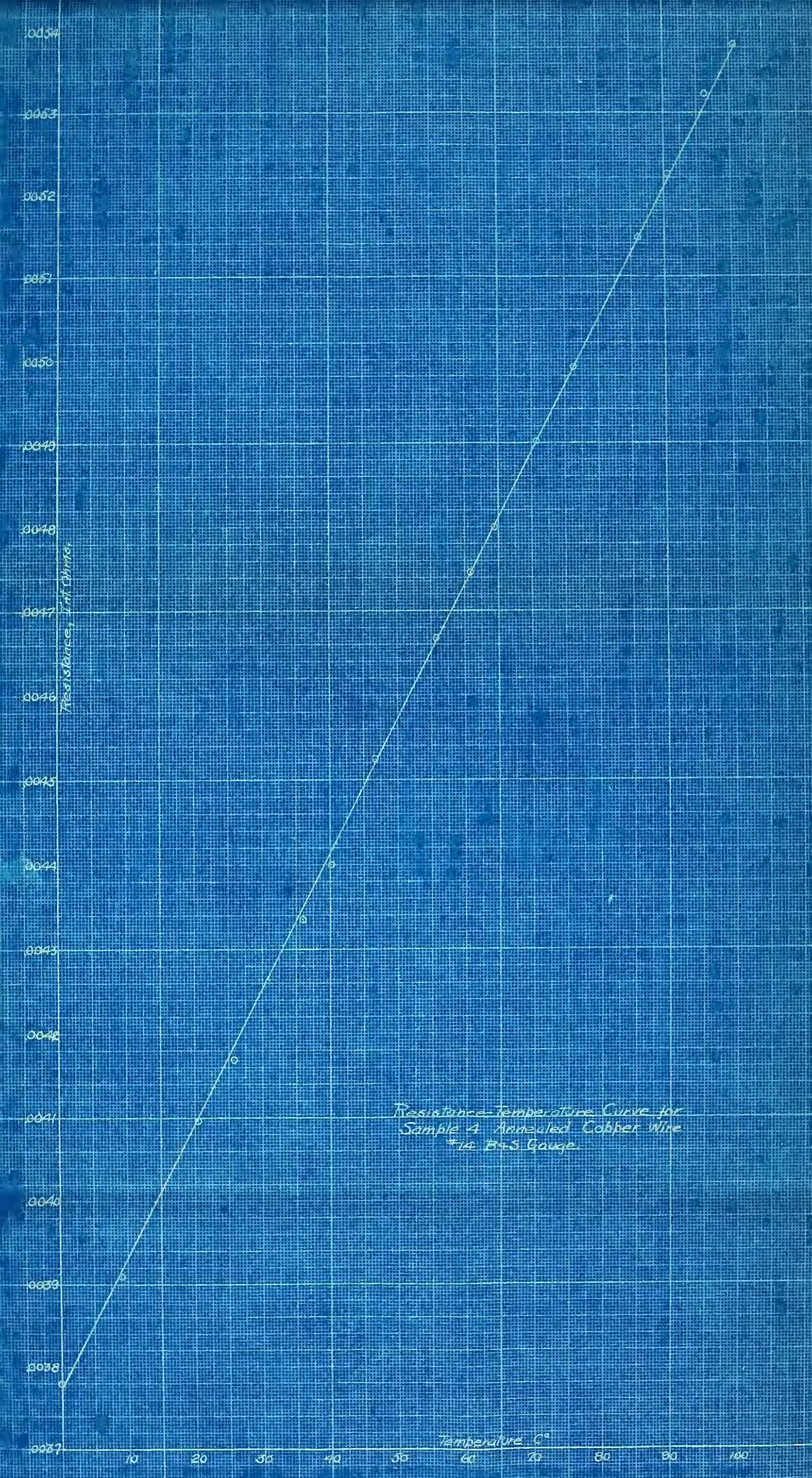


Resistance-Temperature Curve for
Sample 1 Annealed Copper Wire
#10 B&S Gauge
Resistance, Int. Ohms
Temperature C°
.0015
.0016
.0017
.0018
.0019
.0020
.0021
10
20
30
40
50
60
70
80
90
100
Sheet 1



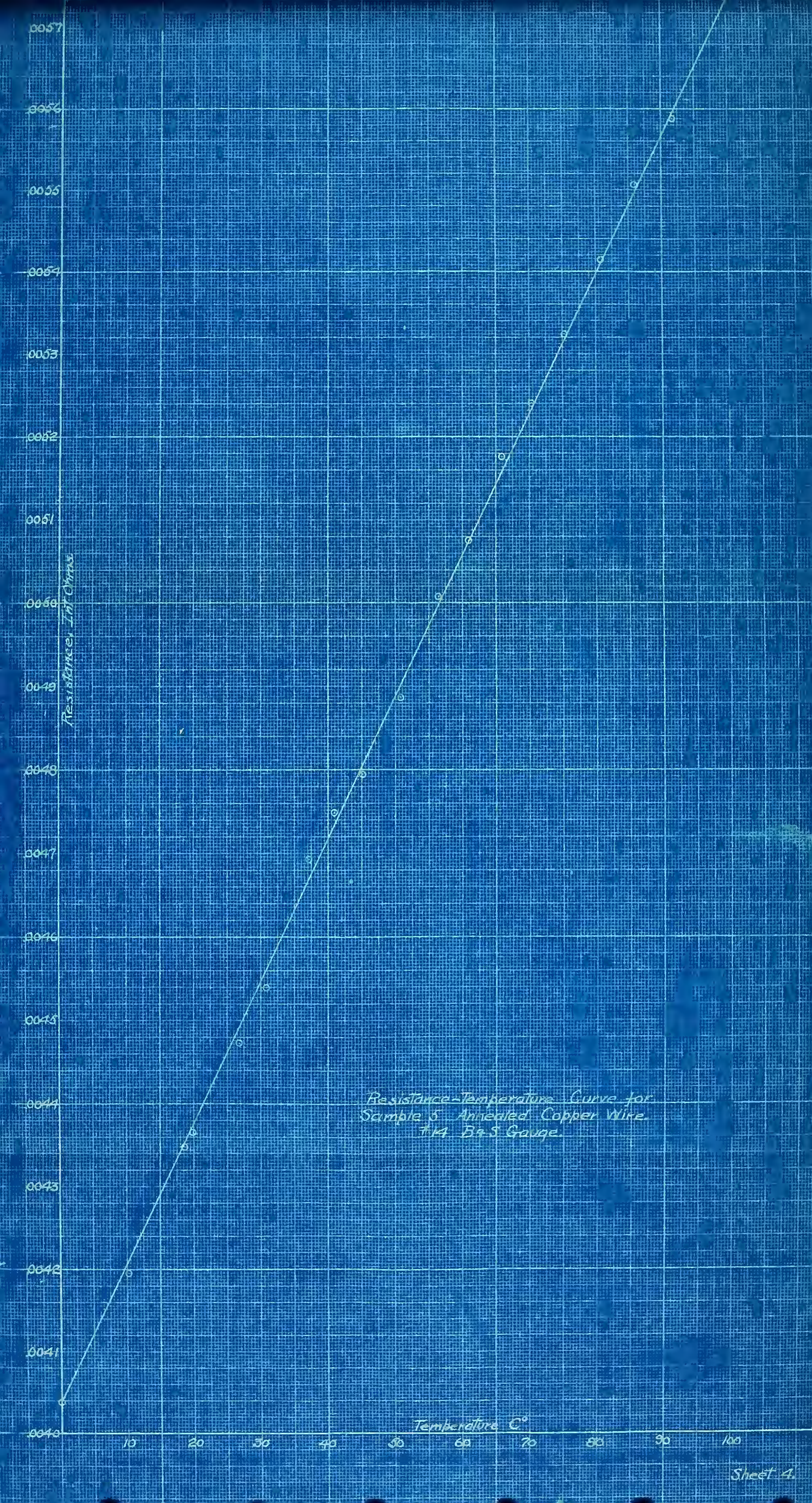
Resistance-Temperature Curve for
Sample 3 Annealed Copper Wire
#14 B&S Gauge.
Resistance, Int Ohms
Temperature C°
.0039
.0040
.0041
.0042
.0043
.0044
.0045
.0046
.0047
.0048
.0049
.0050
.0051
.0052
.0053
.0054
.0055
.0056
10
20
30
40
50
60
70
80
90
100

Sheet 2

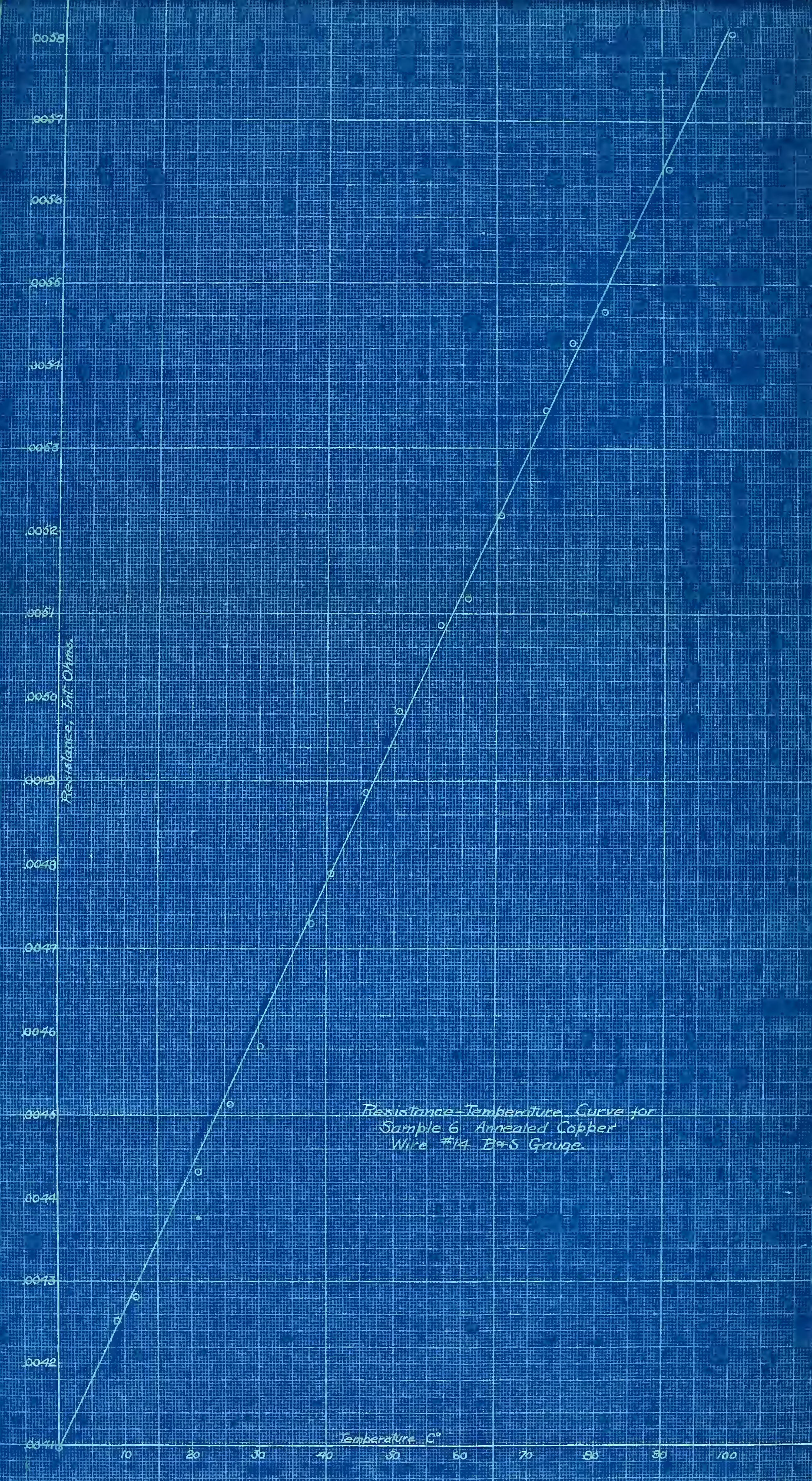


Resistance-Temperature Curve for
Sample 4 Annealed Copper Wire
#14 B&S Gauge
Resistance, Int. Ohms.
Temperature C°
.0037
.0038
.0039
.0040
.0041
.0042
.0043
.0044
.0045
.0046
.0047
.0048
.0049
.0050
.0051
.0052
.0053
.0054
10
20
30
40
50
60
70
80
90
100

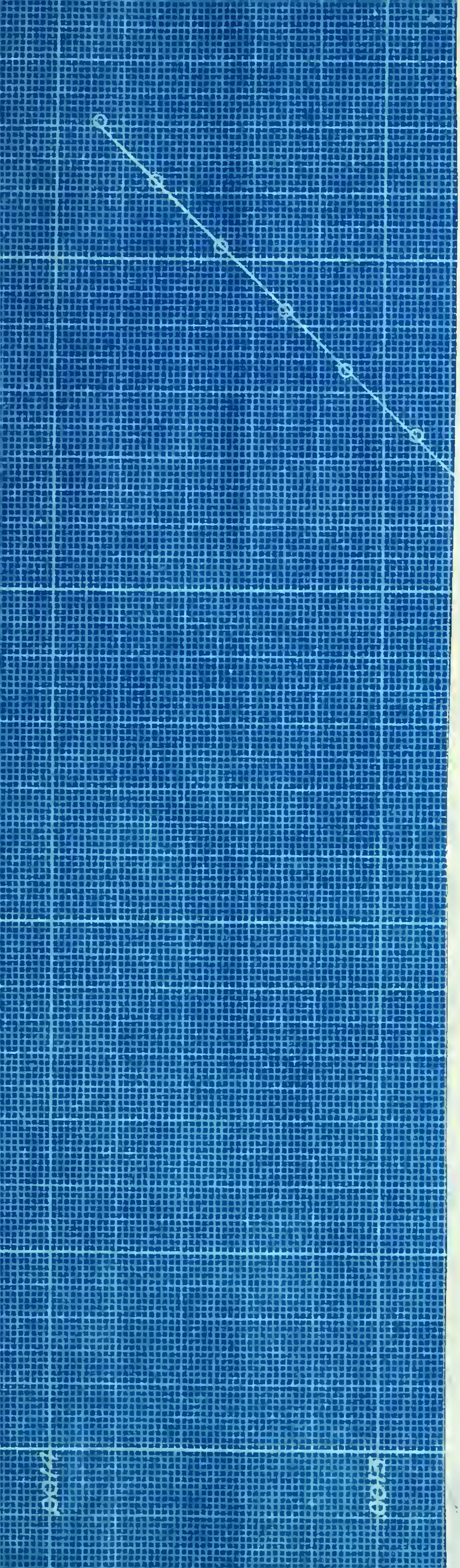
Sheet 5.

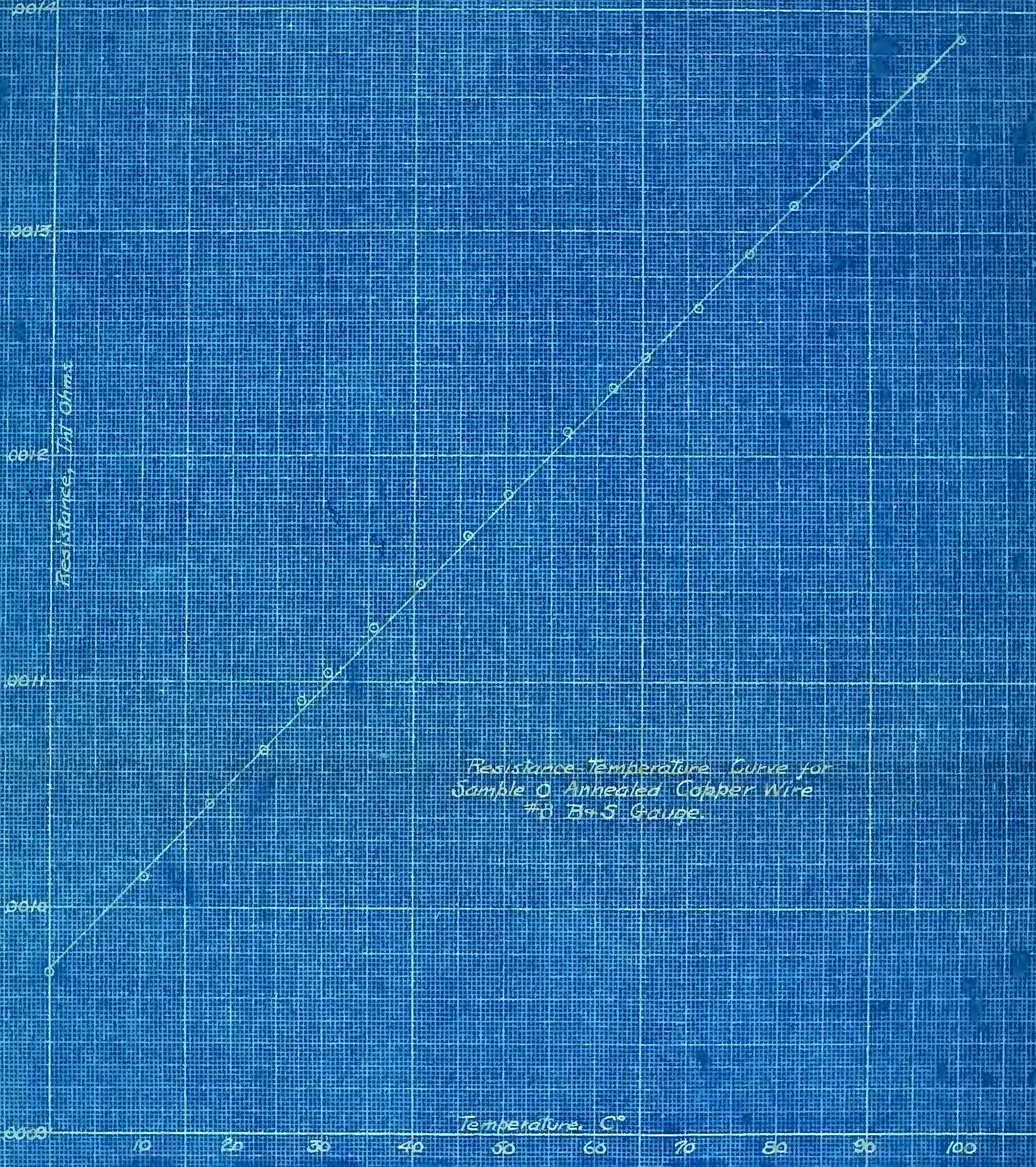


Resistance-Temperature Curve for
Sample 5 Annealed Copper Wire
#14 B&S Gauge
Resistance, Int Ohms
Temperature C°
.0040
.0041
.0042
.0043
.0044
.0045
.0046
.0047
.0048
.0049
.0050
.0051
.0052
.0053
.0054
.0055
.0056
.0057
10
20
30
40
50
60
70
80
90
100
Sheet 4.


Resistance-Temperature Curve for
Sample 6 Annealed Copper
Wire #14 B&S Gauge.
Resistance, Int. Ohms.
Temperature C°
.0058
.0057
.0056
.0055
.0054
.0053
.0052
.0051
.0050
.0049
.0048
.0047
.0046
.0045
.0044
.0043
.0042
.0041
10
20
30
40
50
60
70
80
90
100

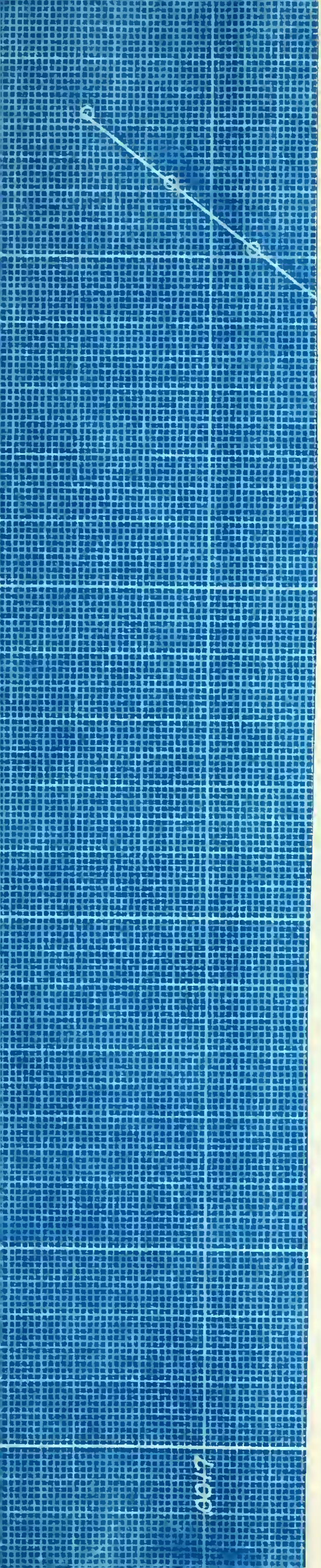
Sheet 5.

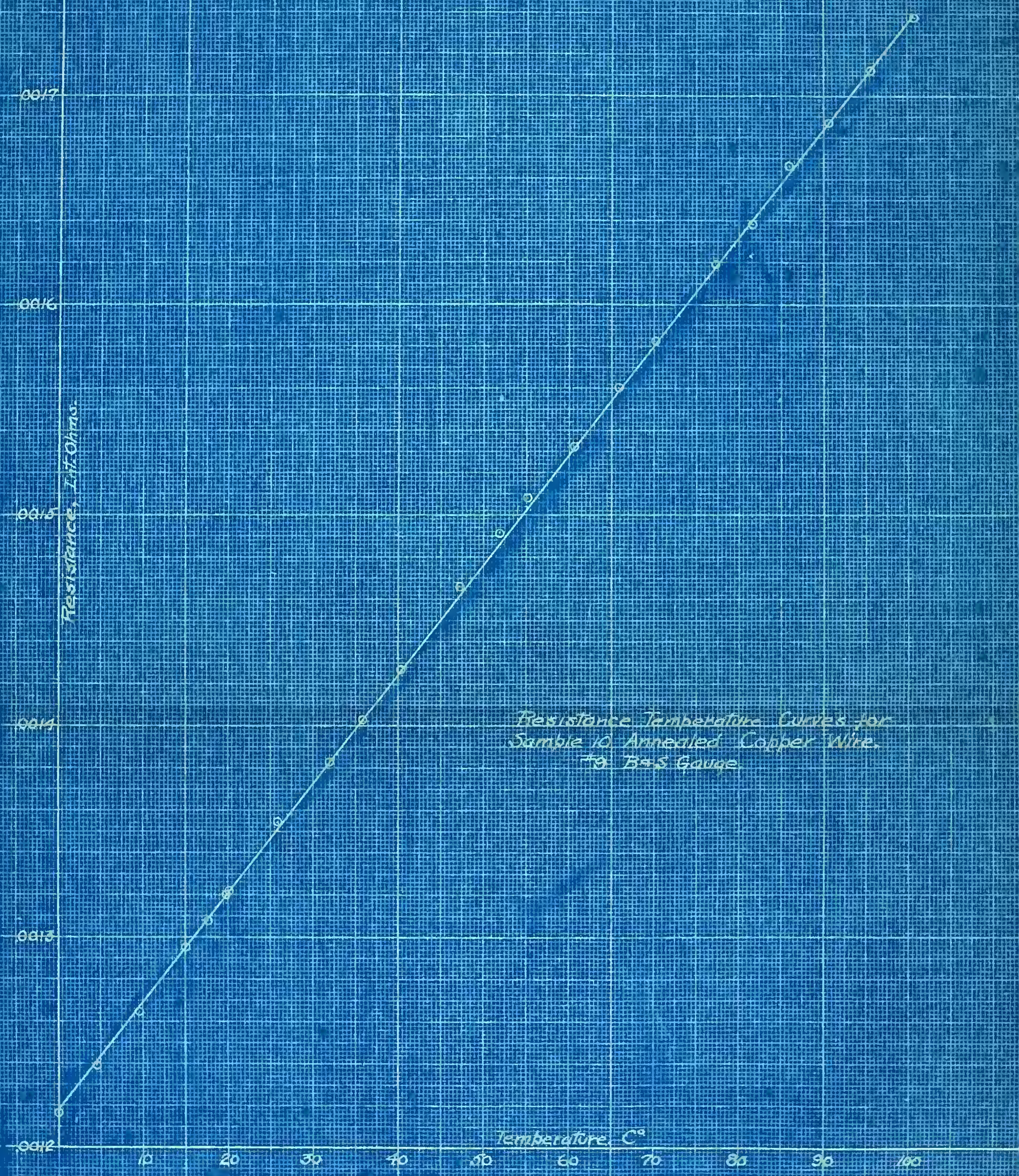




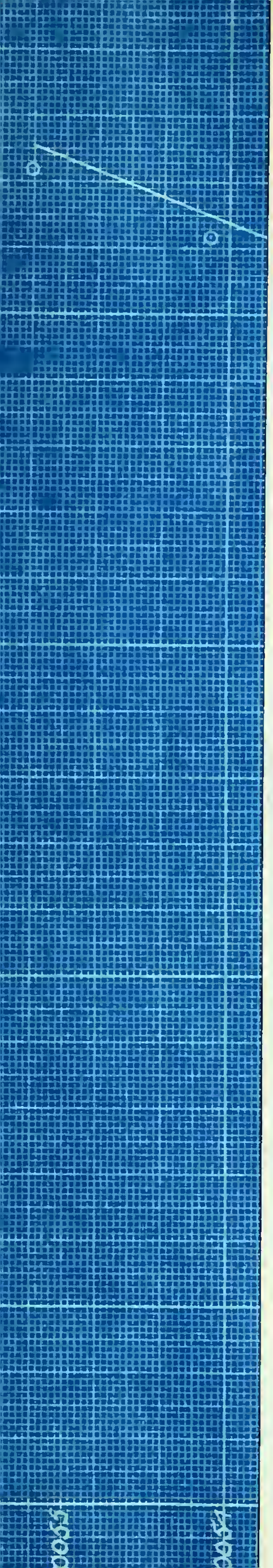
Resistance Temperature Curve for
Sample O Annealed Copper Wire
#8 B+S Gauge.
Resistance, Int Ohms
.0014
.0013
.0012
.0011
.0010
.0009
Temperature. C°
10
20
30
40
50
60
70
80
90
100

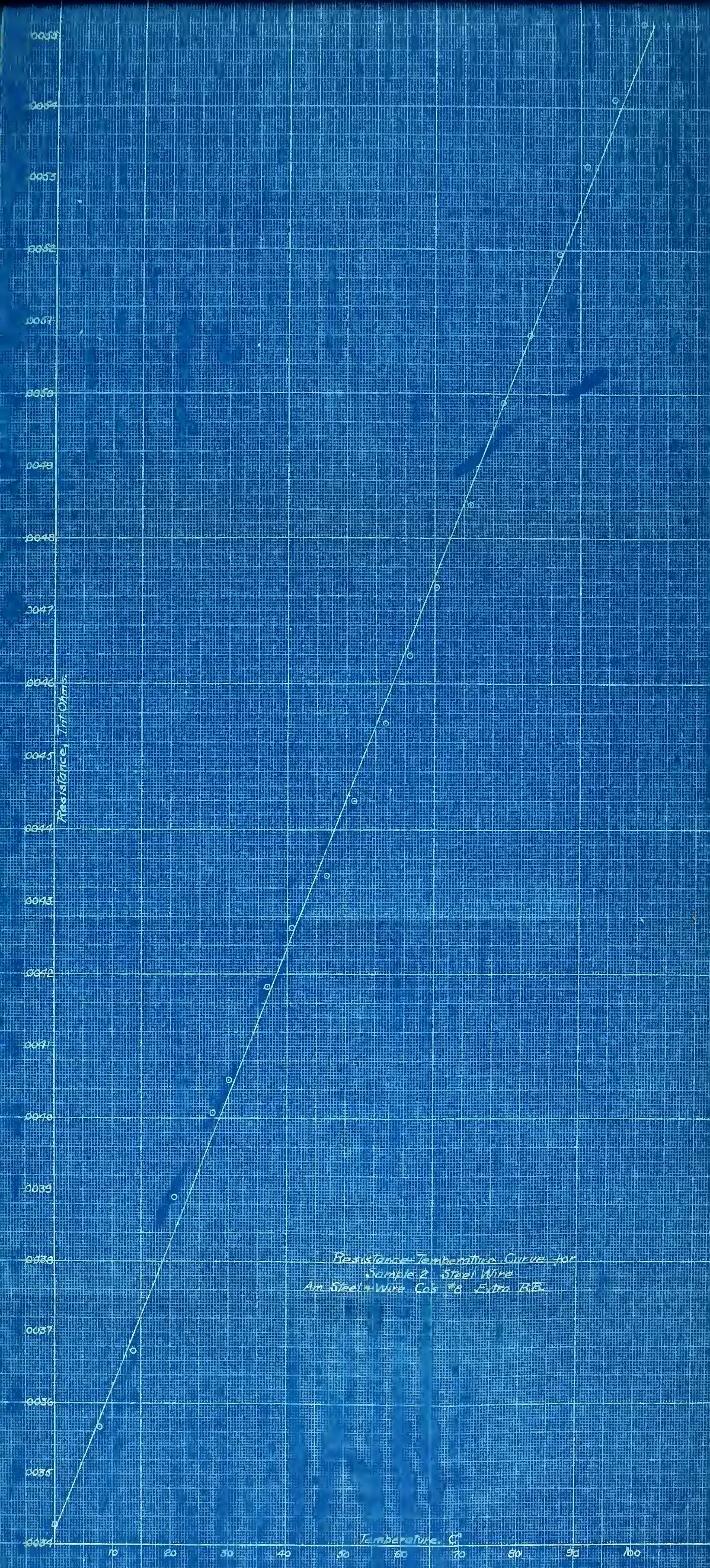
Sheet 6.




Resistance Temperature Curves for
Sample 10 Annealed Copper Wire.
#9 B&S Gauge
Resistance, Int. Ohms.
.0017
.0016
.0015
.0014
.0013
.0012
Temperature, C°
10
20
30
40
50
60
70
80
90
100

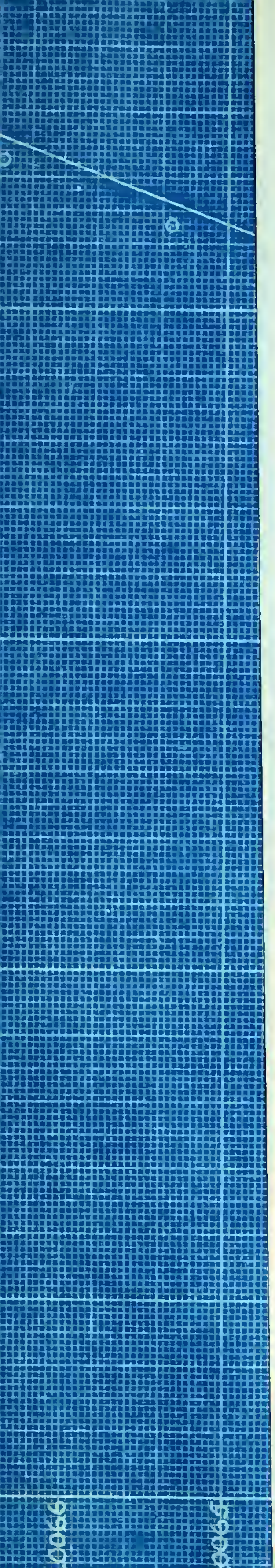
Sheet 2.

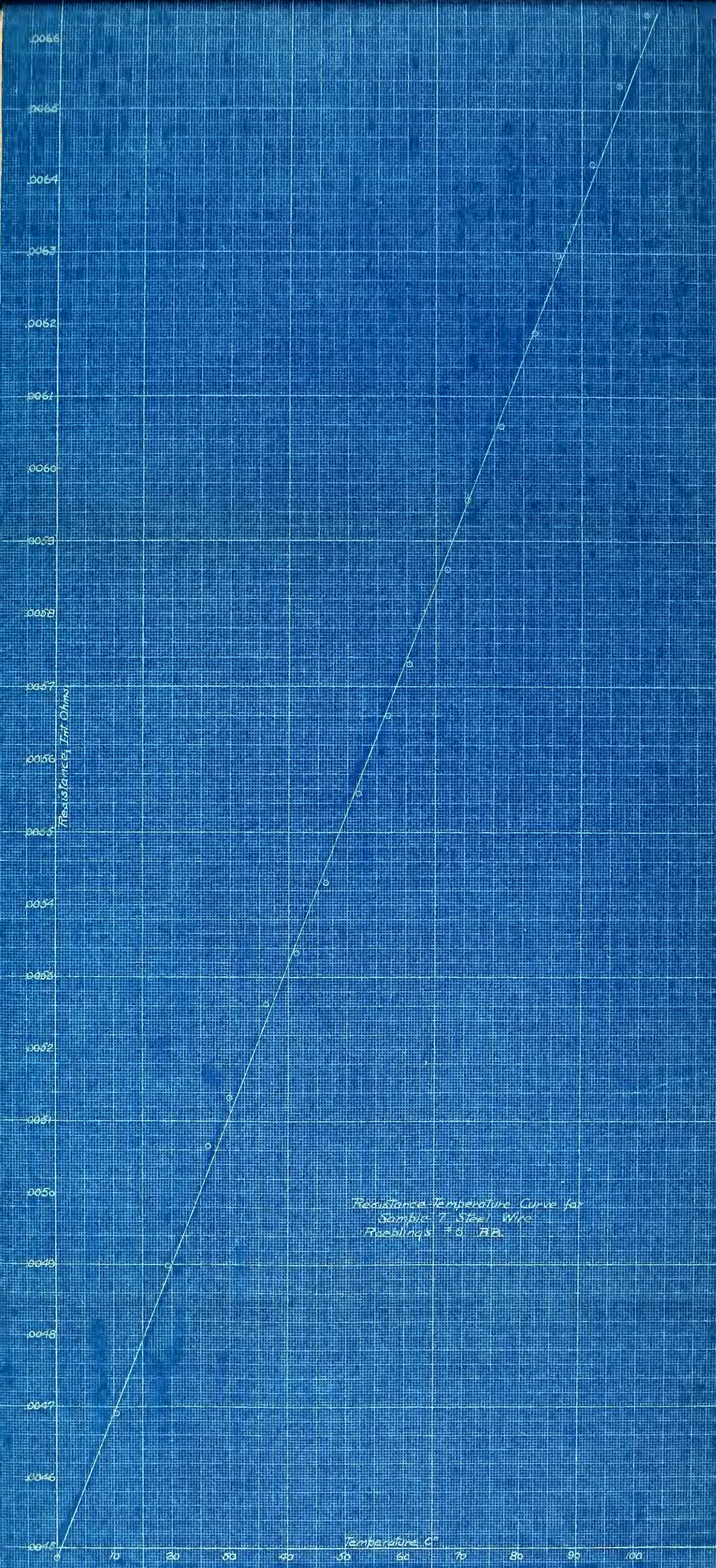




Resistance-Temperature Curve for
Sample 2 Steel Wire
Am. Steel & Wire Co's #6 Extra B.B.
Resistance, Int. Ohms.
Temperature, C°
.0055
.0054
.0053
.0052
.0051
.0050
.0049
.0048
.0047
.0046
.0045
.0044
.0043
.0042
.0041
.0040
.0039
.0038
.0037
.0036
.0035
.0034
10
20
30
40
50
60
70
80
90
100

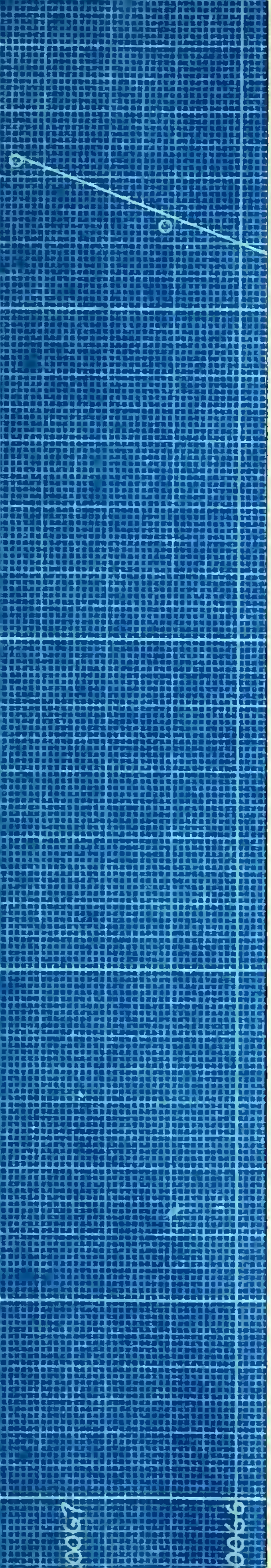
Sheet 8.

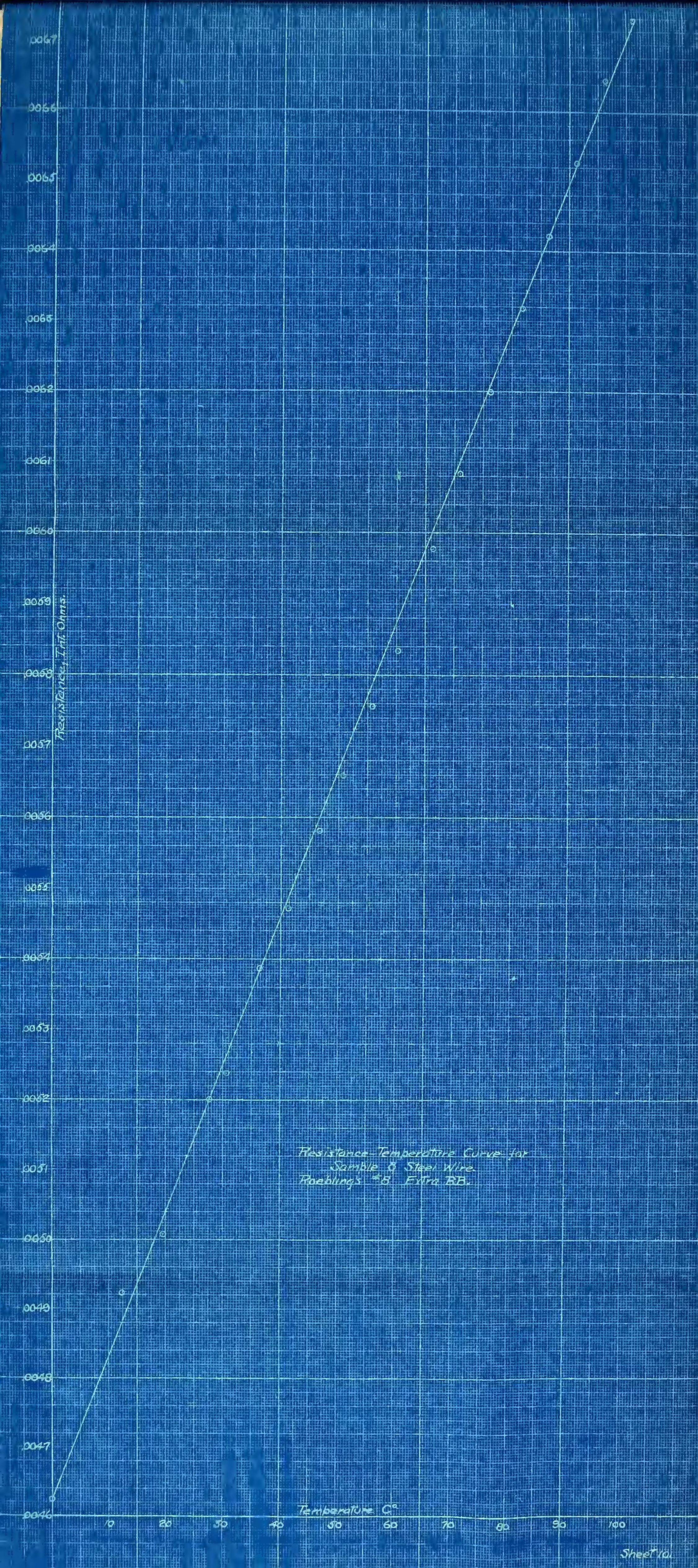




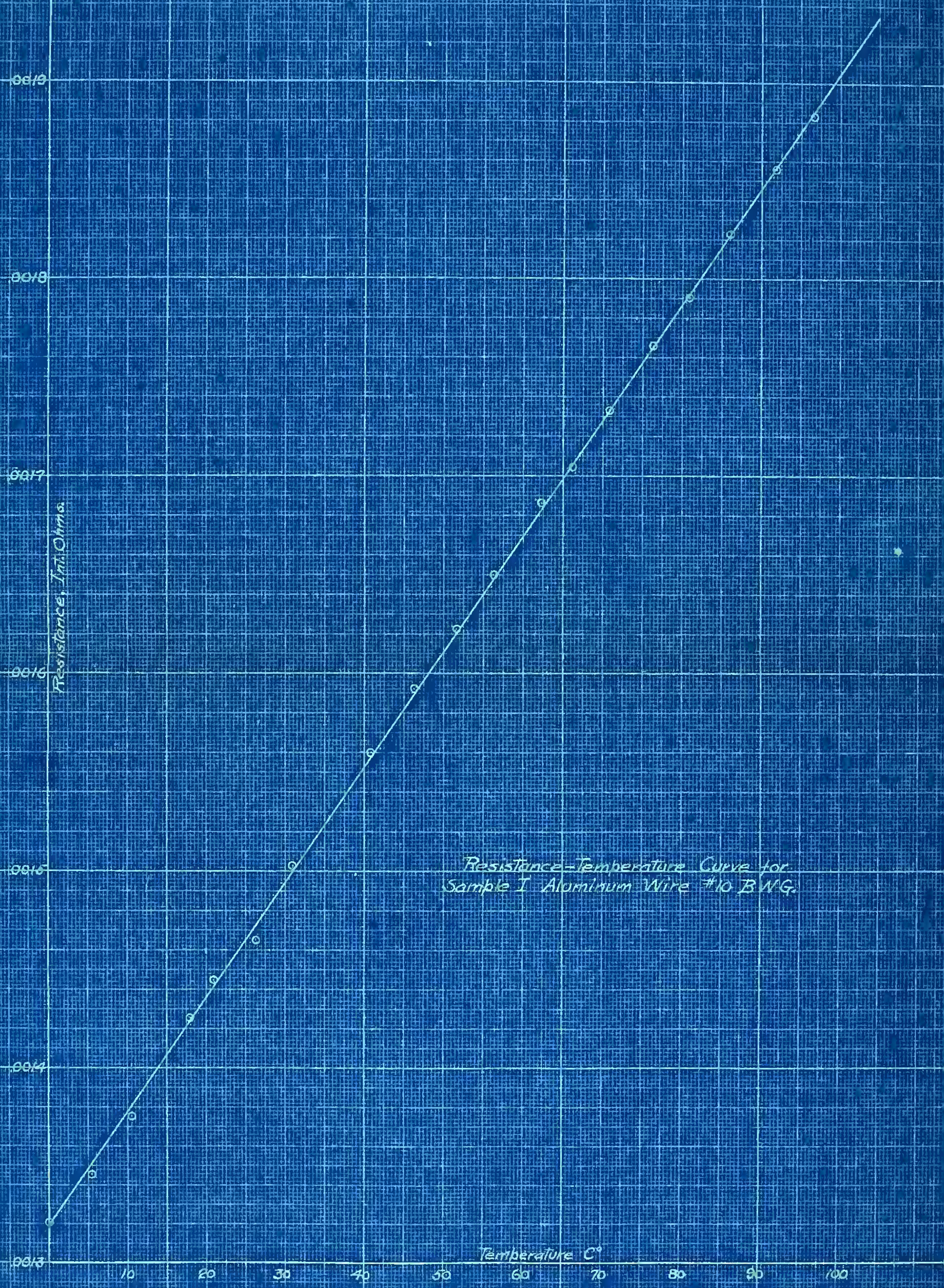
Resistance Temperature Curve for
Sample 7. Steel Wire
Roeblings #8 B.B.
Resistance, Int Ohms
Temperature C°

Sheet 9.

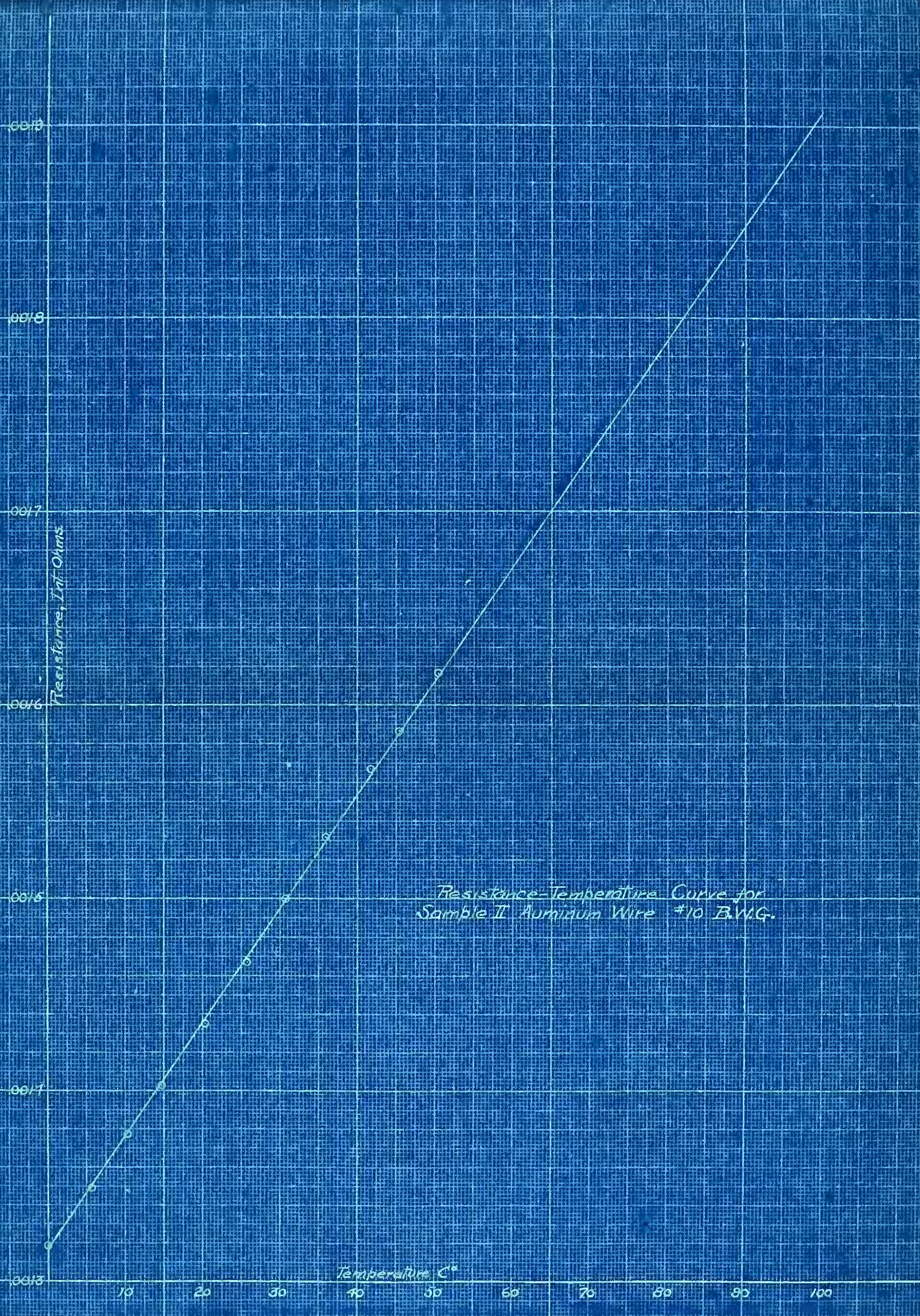




Resistance-Temperature Curve for
Sample 8 Steel Wire
Roebling's "8" Extra BB.
Resistance, Int. Ohms.
Temperature C°
.0067
.0066
.0065
.0064
.0063
.0062
.0061
.0060
.0059
.0058
.0057
.0056
.0055
.0054
.0053
.0052
.0051
.0050
.0049
.0048
.0047
.0046
10
20
30
40
50
60
70
80
90
100
Sheet 10.

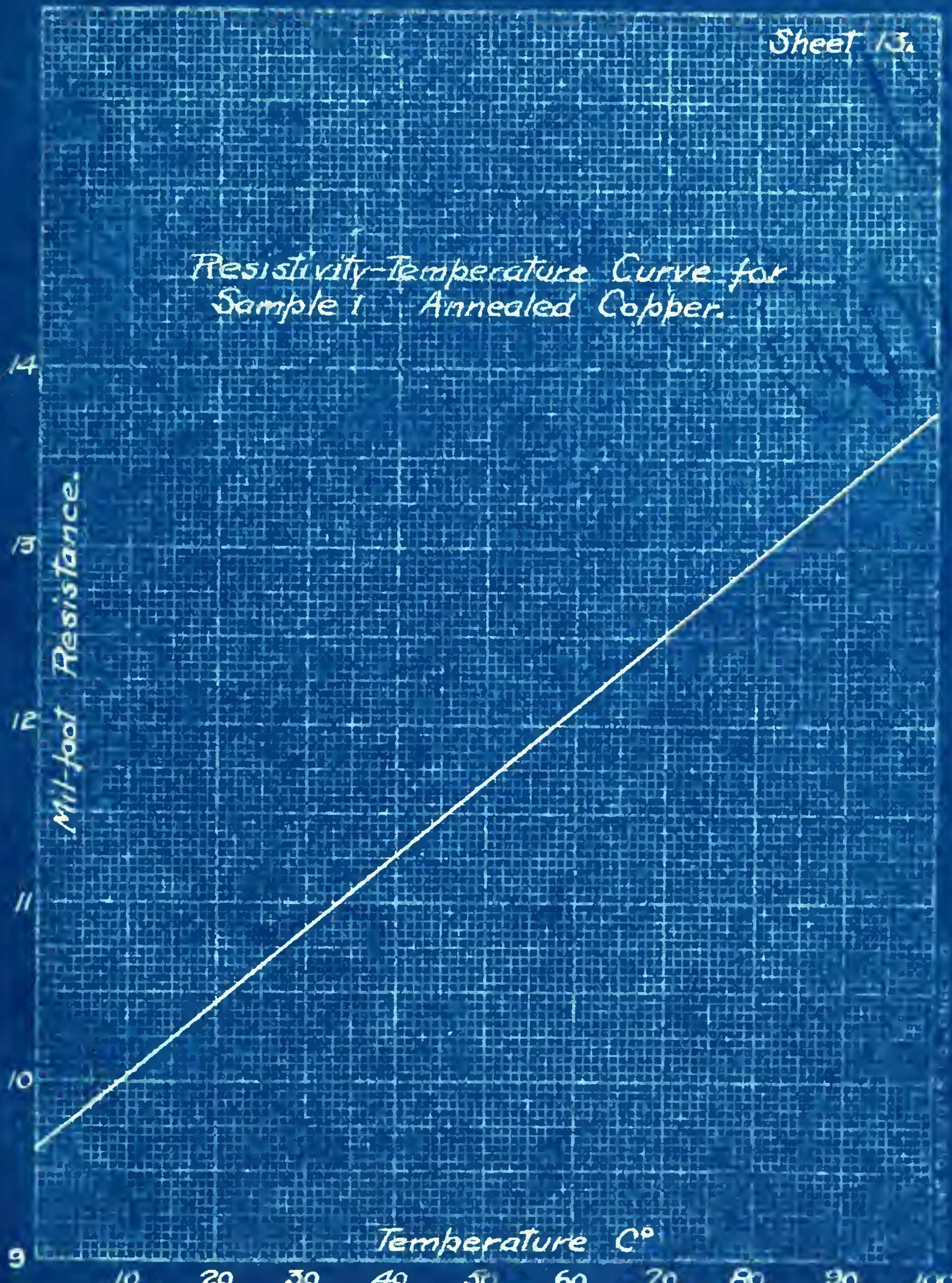

Resistance-Temperature Curve for
Sample I Aluminum Wire #10 B.W.G.
Resistance, Int. Ohms.
Temperature C°
.0019
.0018
.0017
.0016
.0015
.0014
.0013
10
20
30
40
50
60
70
80
90
100

Sheet 11

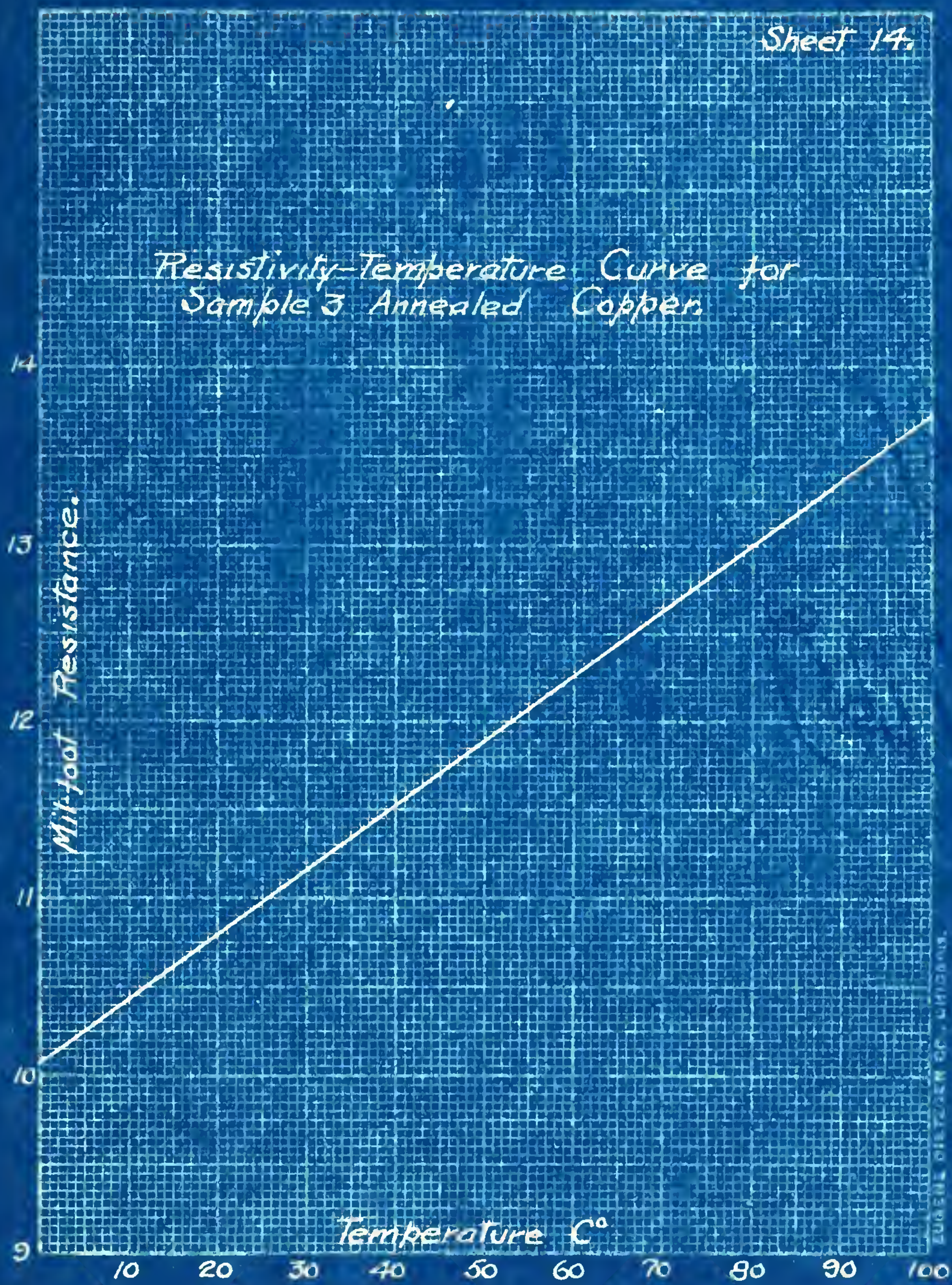


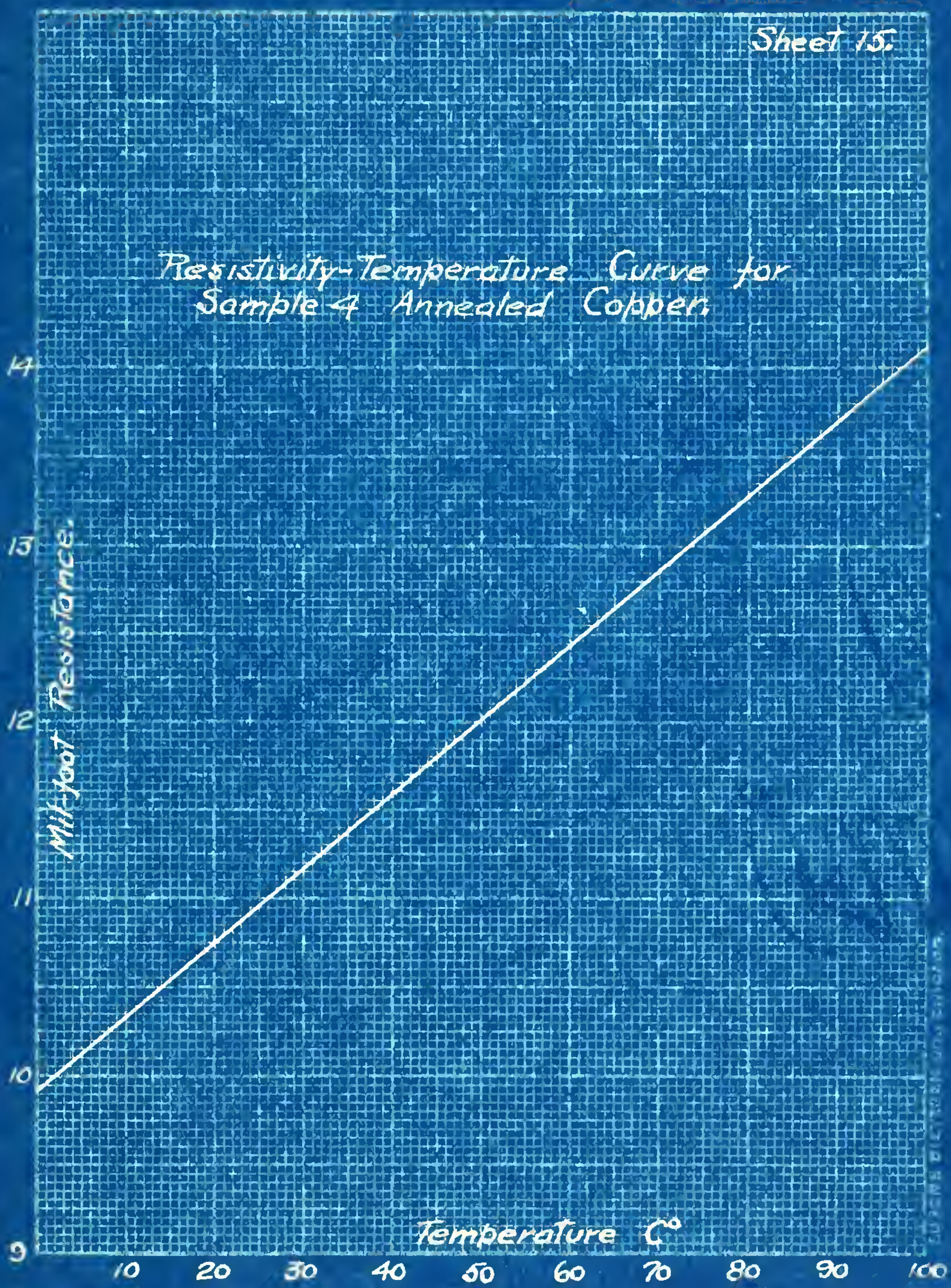
Resistance-Temperature Curve for
Sample II Aluminium Wire #10 B.W.G.
Resistance, Int. Ohms
Temperature C°
.0013
.0014
.0015
.0016
.0017
.0018
.0019
10
20
30
40
50
60
70
80
90
100

Sheet 12.

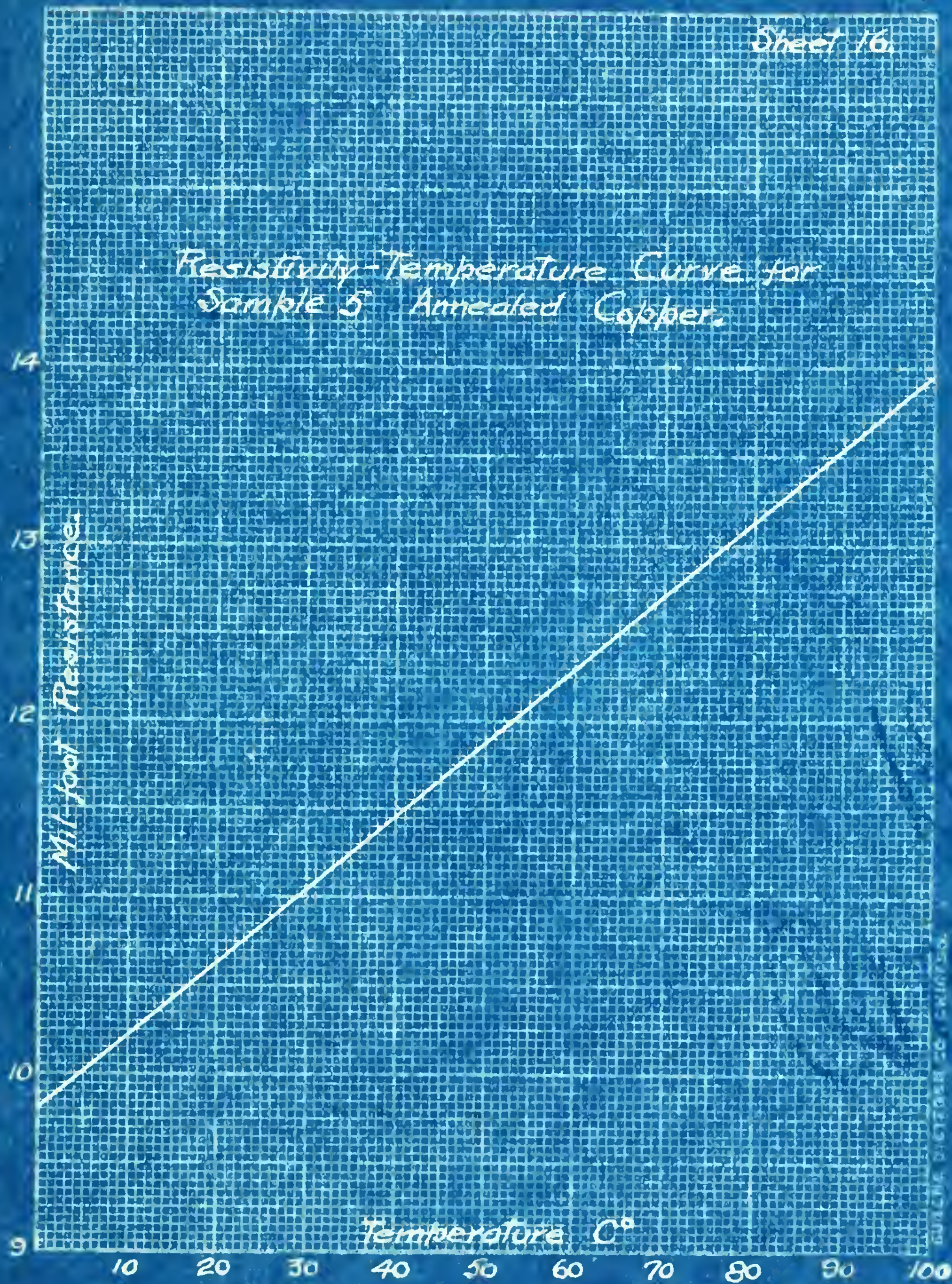


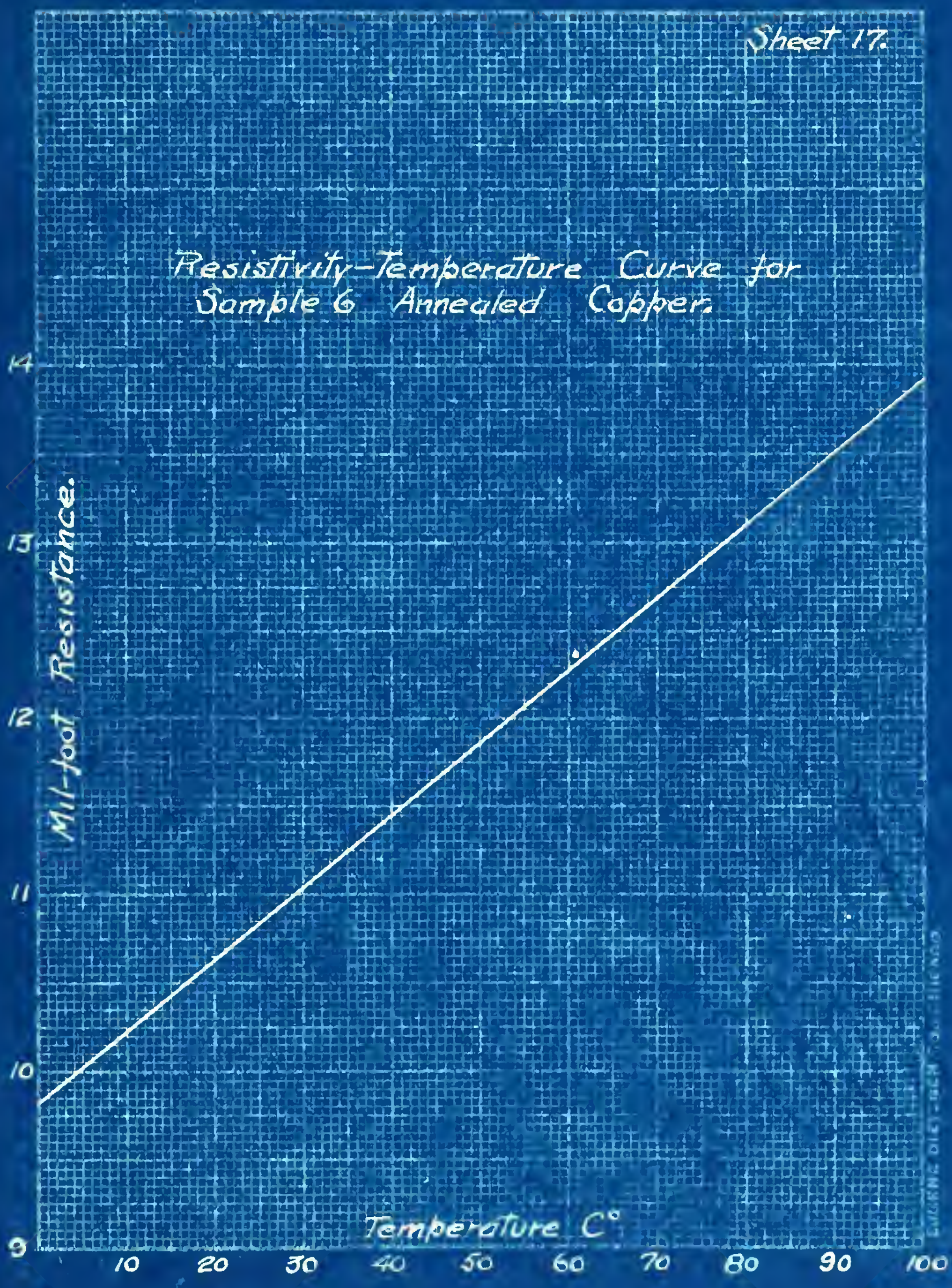
Sheet 13.
Resistivity-Temperature Curve for
Sample 1 Annealed Copper.
Mil-foot Resistance.
14
13
12
11
10
9
Temperature C°
10
20
30
40
50
60
70
80
90
100

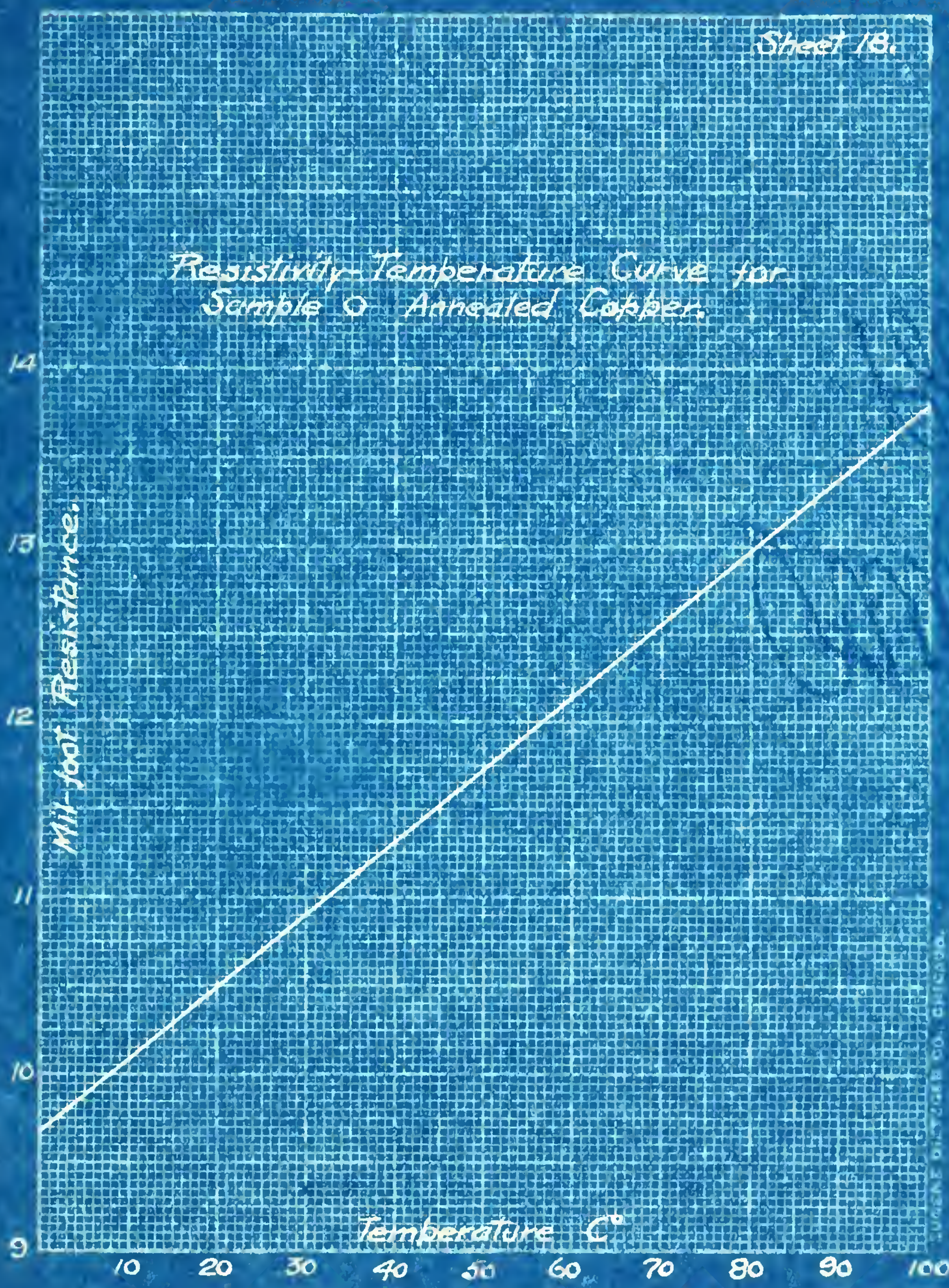

Sheet 14.
Resistivity-Temperature Curve for
Sample 3 Annealed Copper.
Mil-foot Resistance.
14
13
12
11
10
9
Temperature C°
10
20
30
40
50
60
70
80
90
100

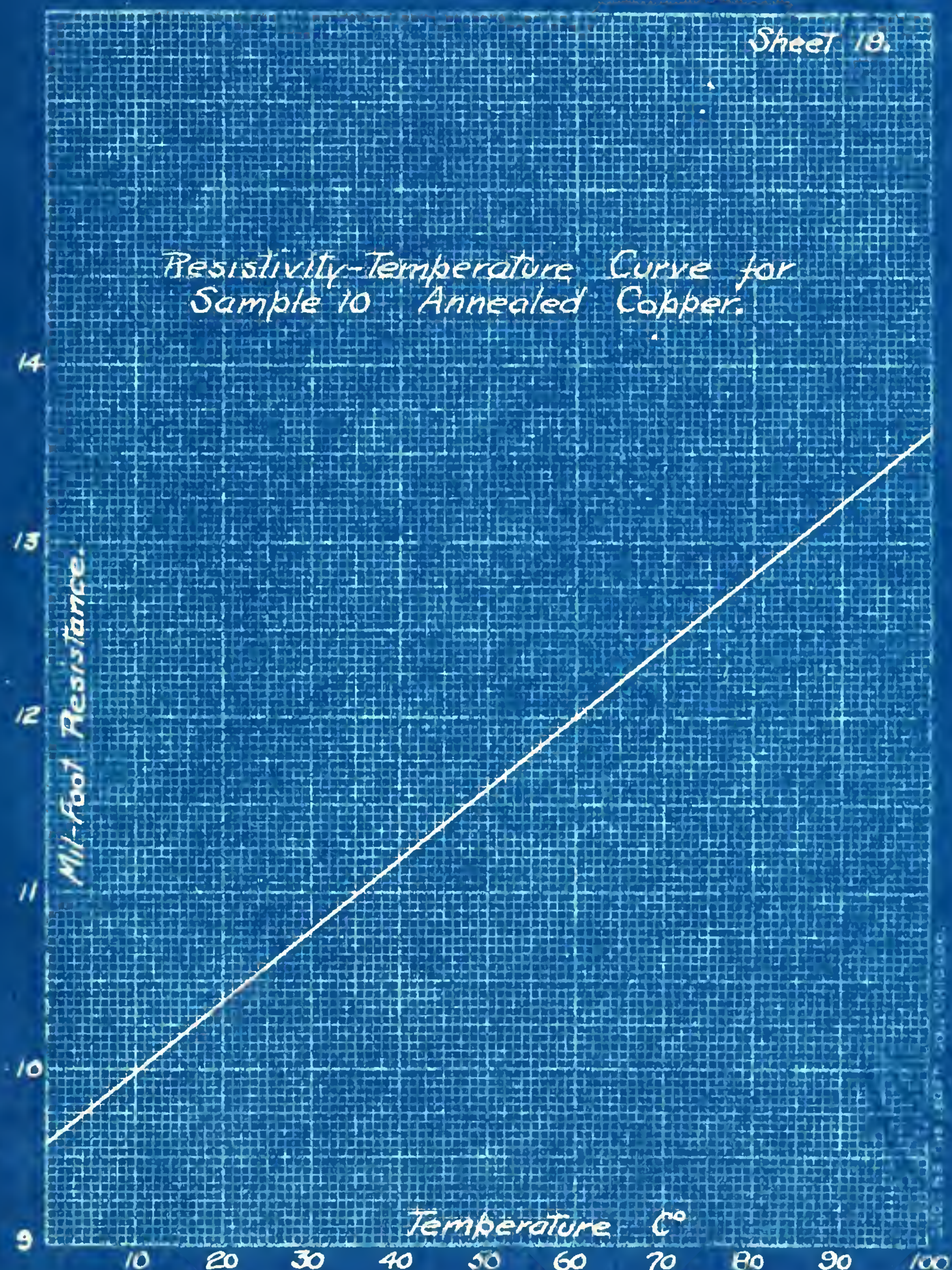


Sheet 15.
Resistivity-Temperature Curve for
Sample 4 Annealed Copper.
Mil-foot Resistance.
14
13
12
11
10
9
Temperature C°
10
20
30
40
50
60
70
80
90
100


Sheet 16.
Resistivity-Temperature Curve for
Sample 5 Annealed Copper.
Mil-foot Resistance.
Temperature C°
14
13
12
11
10
9
10
20
30
40
50
60
70
80
90
100

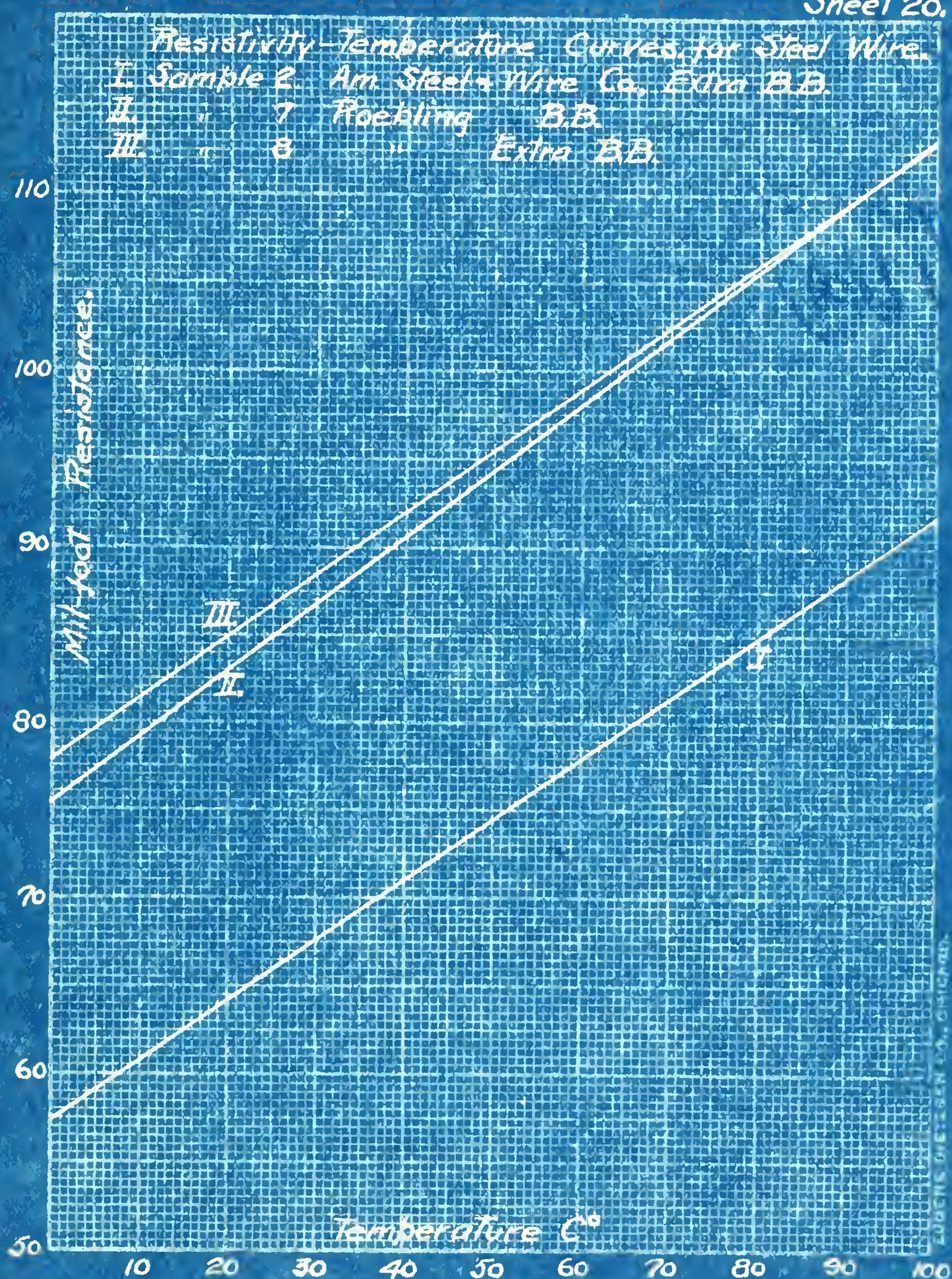

Sheet 17.
Resistivity-Temperature Curve for
Sample 6 Annealed Copper.
Mil-foot Resistance.
Temperature C°
9
10
11
12
13
14
10
20
30
40
50
60
70
80
90
100

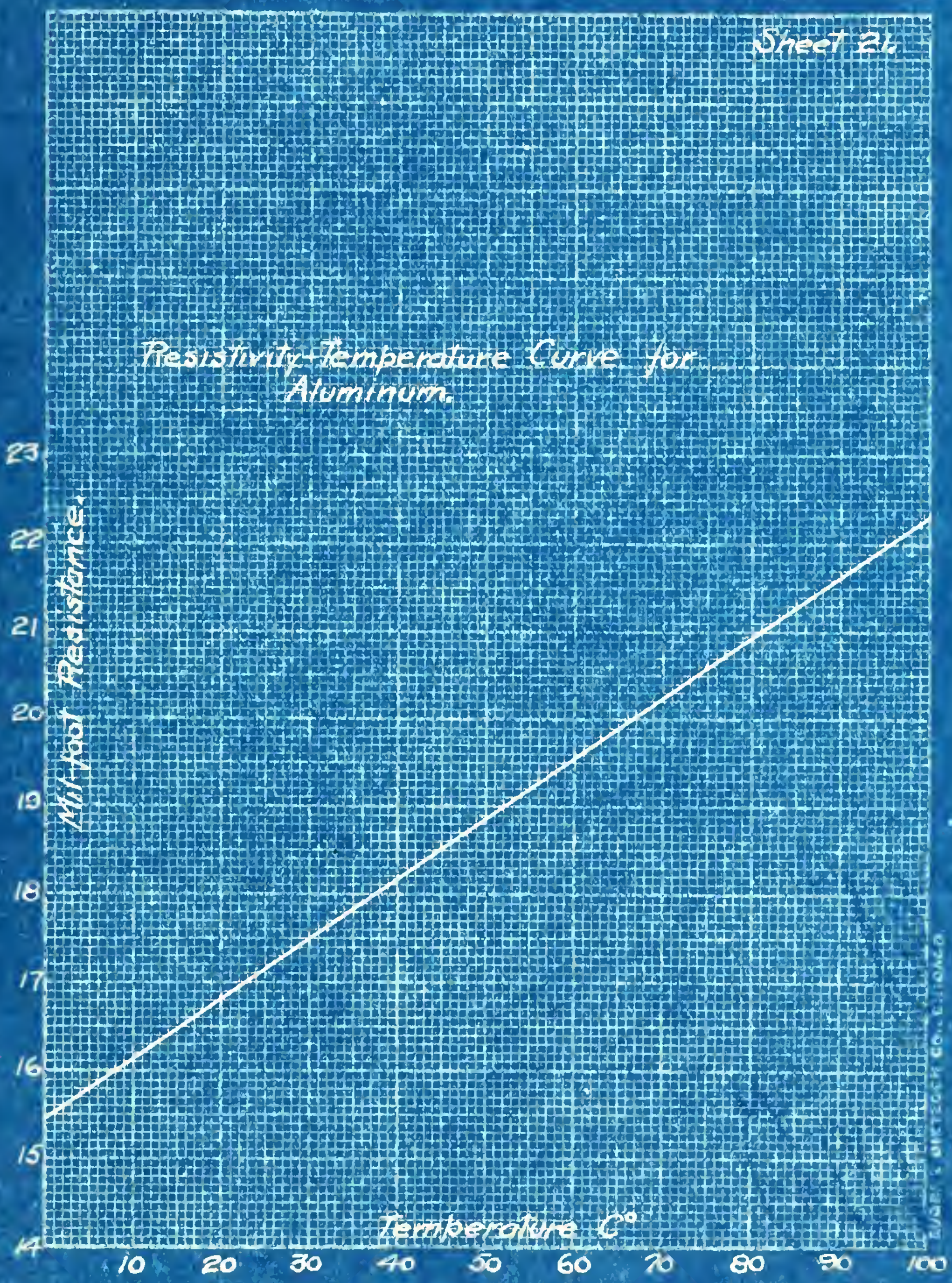

Sheet 18.
Resistivity-Temperature Curve for
Sample O Annealed Copper.
Mil-foot Resistance.
14
13
12
11
10
9
Temperature C°
10
20
30
40
50
60
70
80
90
100

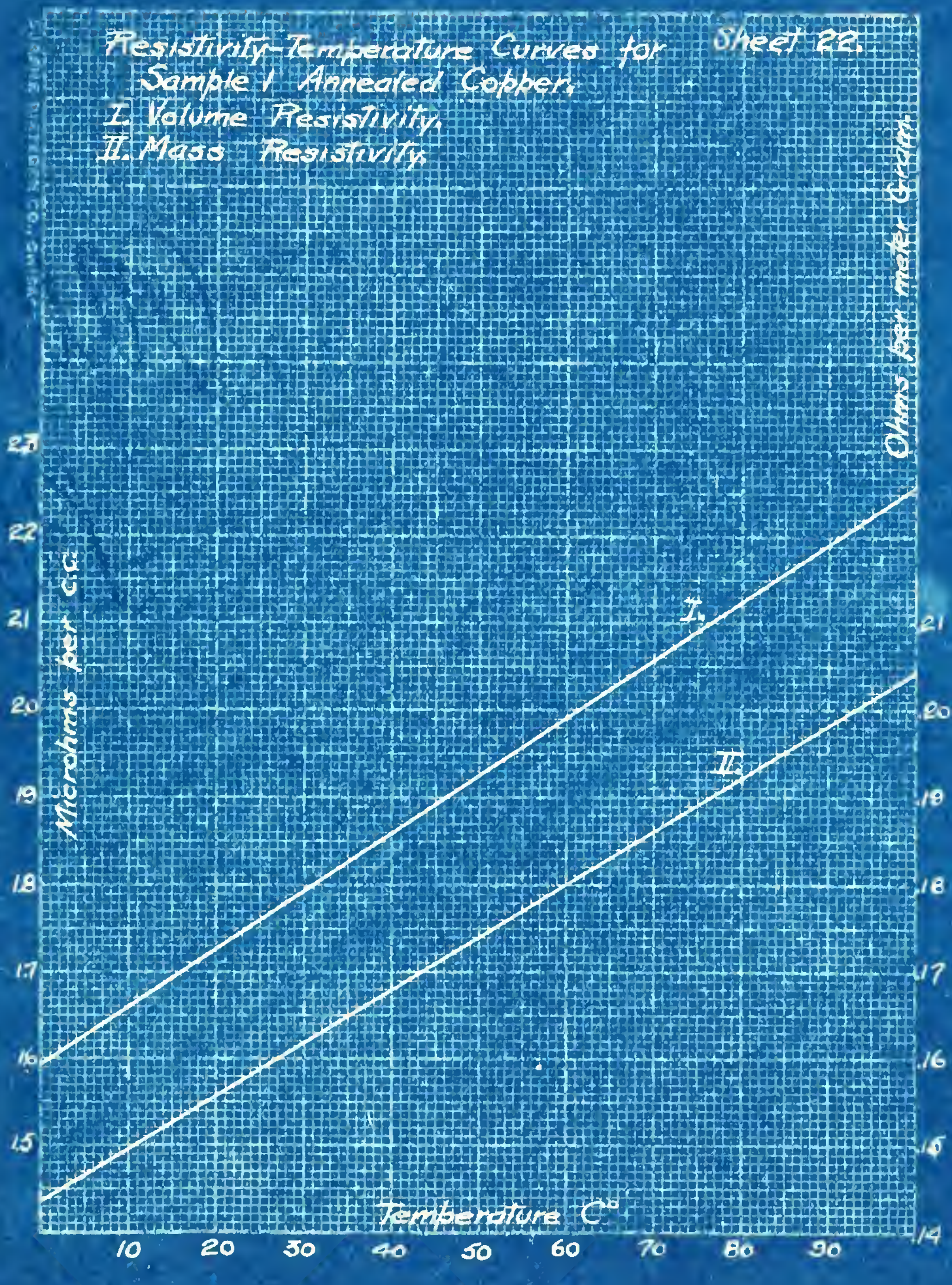


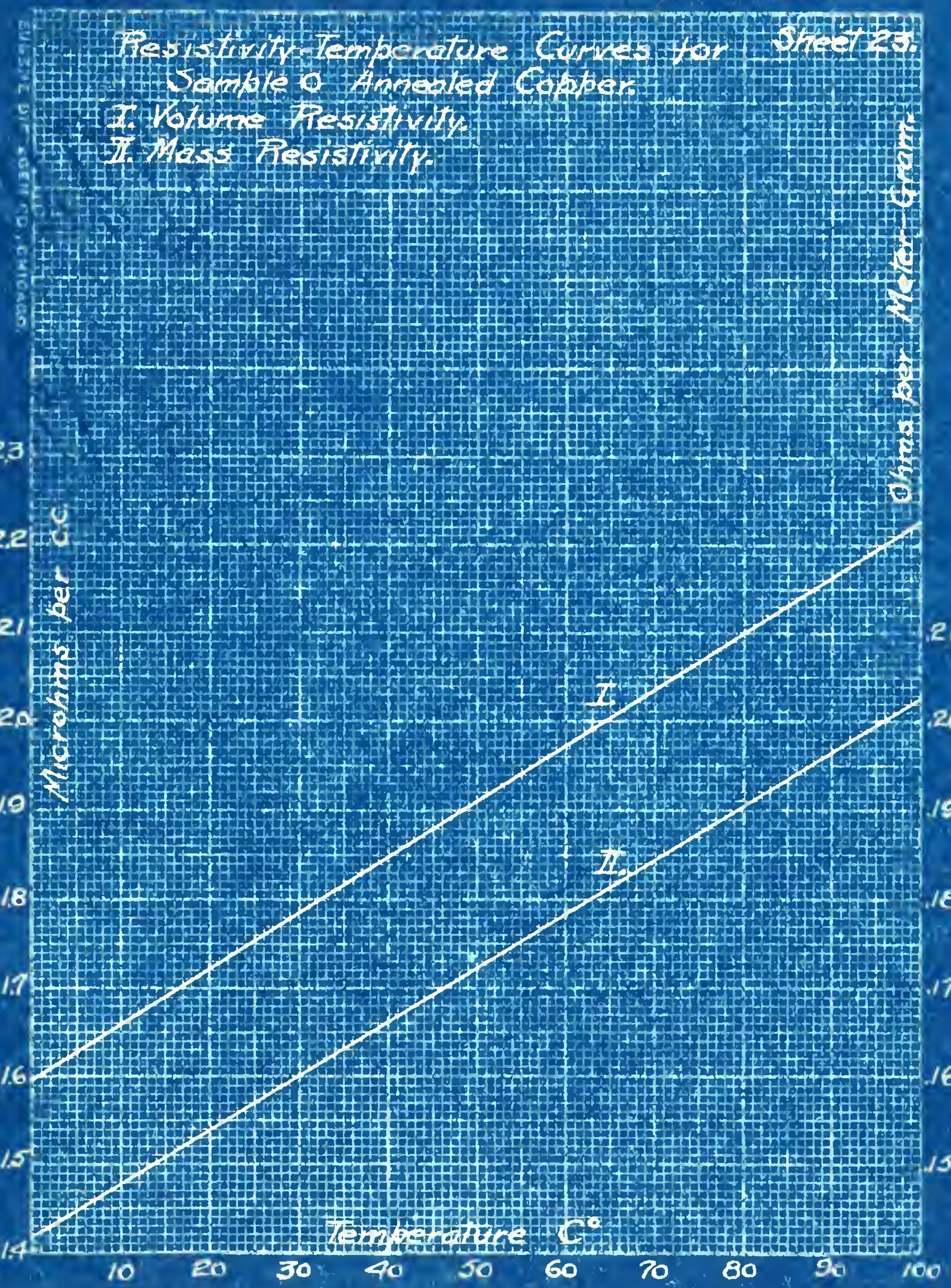
Sheet 18.
Resistivity-Temperature Curve for
Sample 10 Annealed Copper.
Mil-foot Resistance.
Temperature C°
9
10
11
12
13
14
10
20
30
40
50
60
70
80
90
100

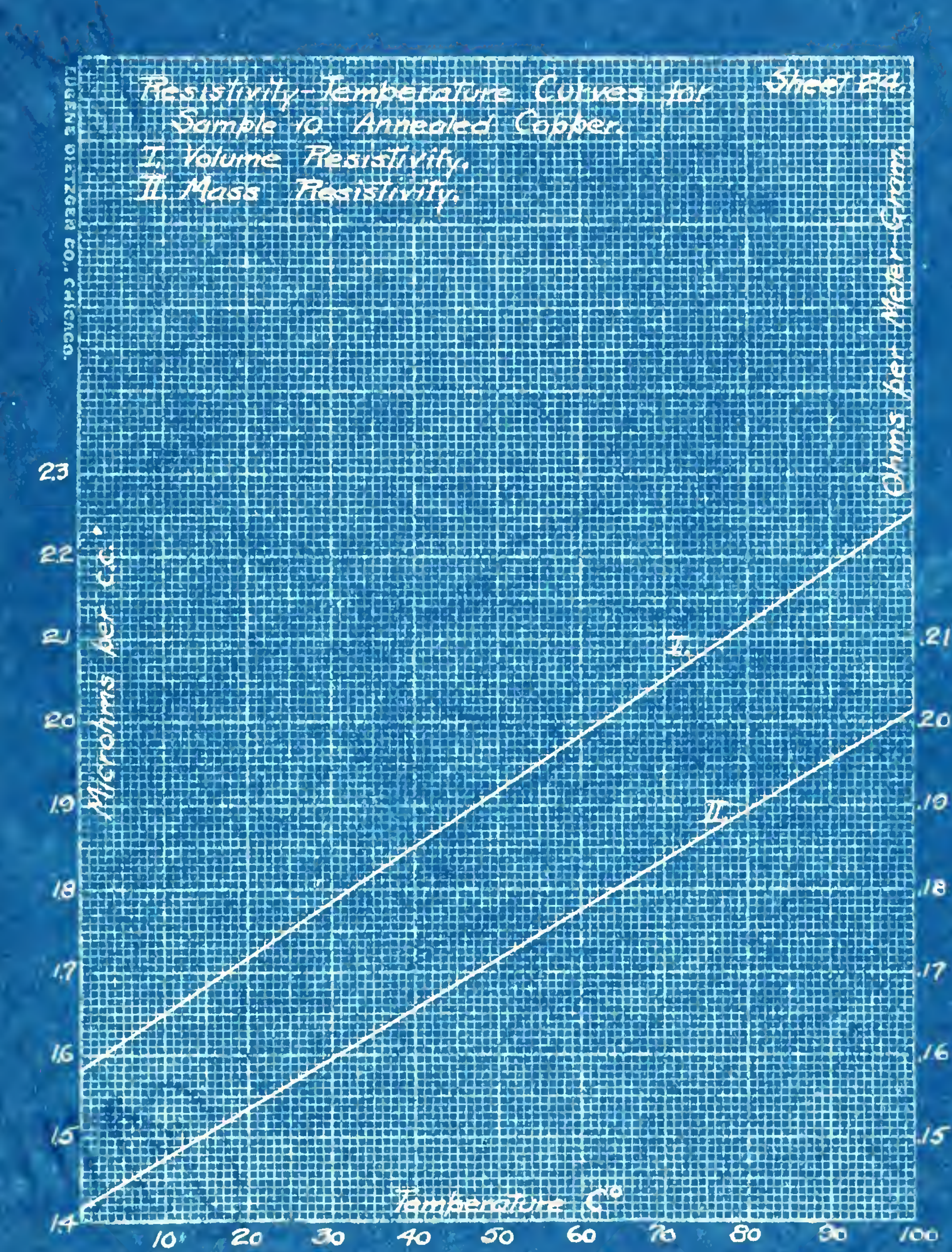
Sheet 20.


Resistivity-Temperature Curves for Steel Wire.
I. Sample 2. Am. Steel & Wire Co. Extra B.B.
II. " 7 Roebling B.B.
III. " 8 " Extra B.B.
Mil-foot Resistance.
110
100
90
80
70
60
50
III.
II.
I.
Temperature C°
10
20
30
40
50
60
70
80
90
100

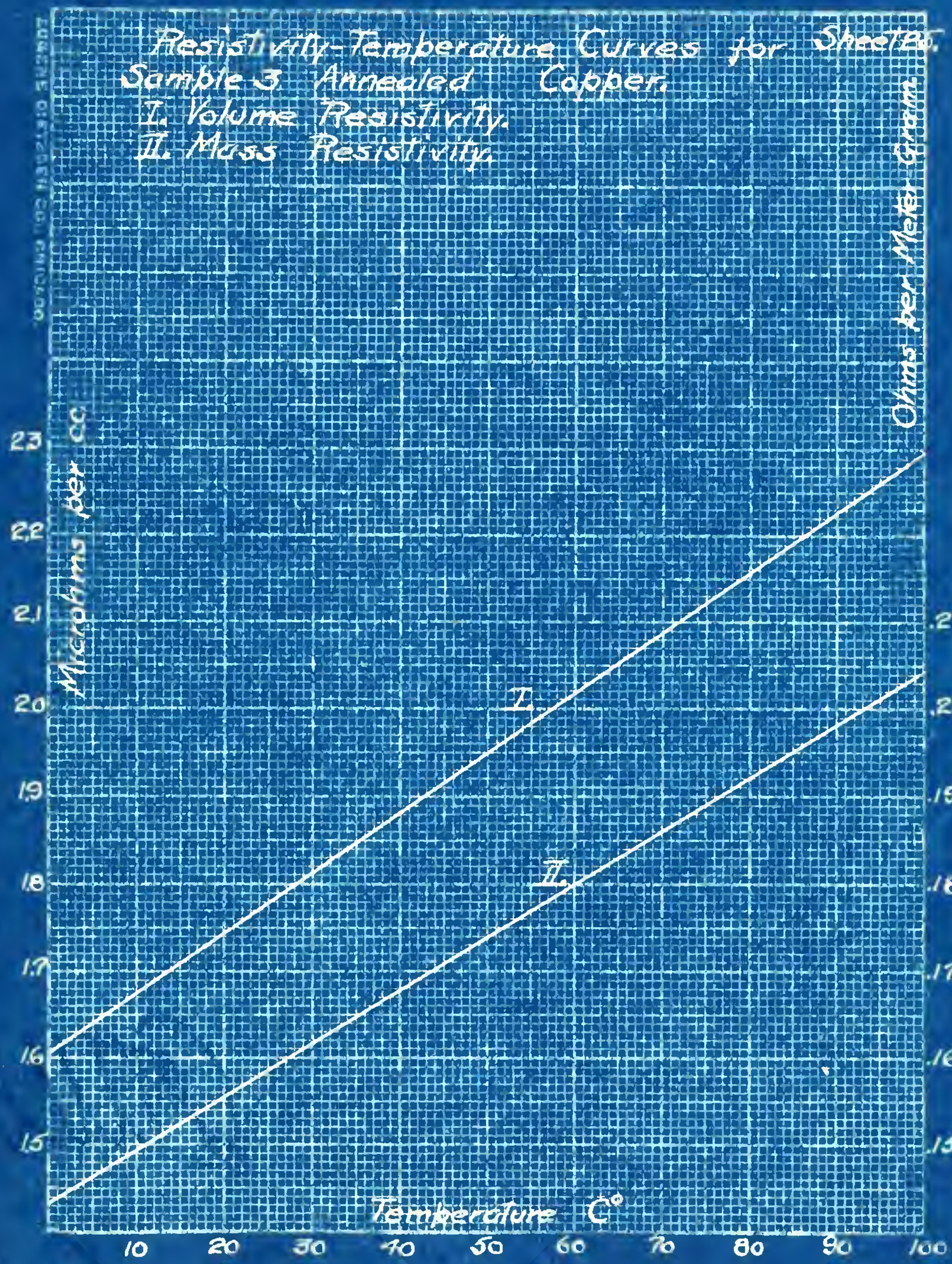

Sheet 21.
Resistivity-Temperature Curve for Aluminum.
Mil-foot Resistance.
Temperature C°
14
15
16
17
18
19
20
21
22
23
10
20
30
40
50
60
70
80
90
100

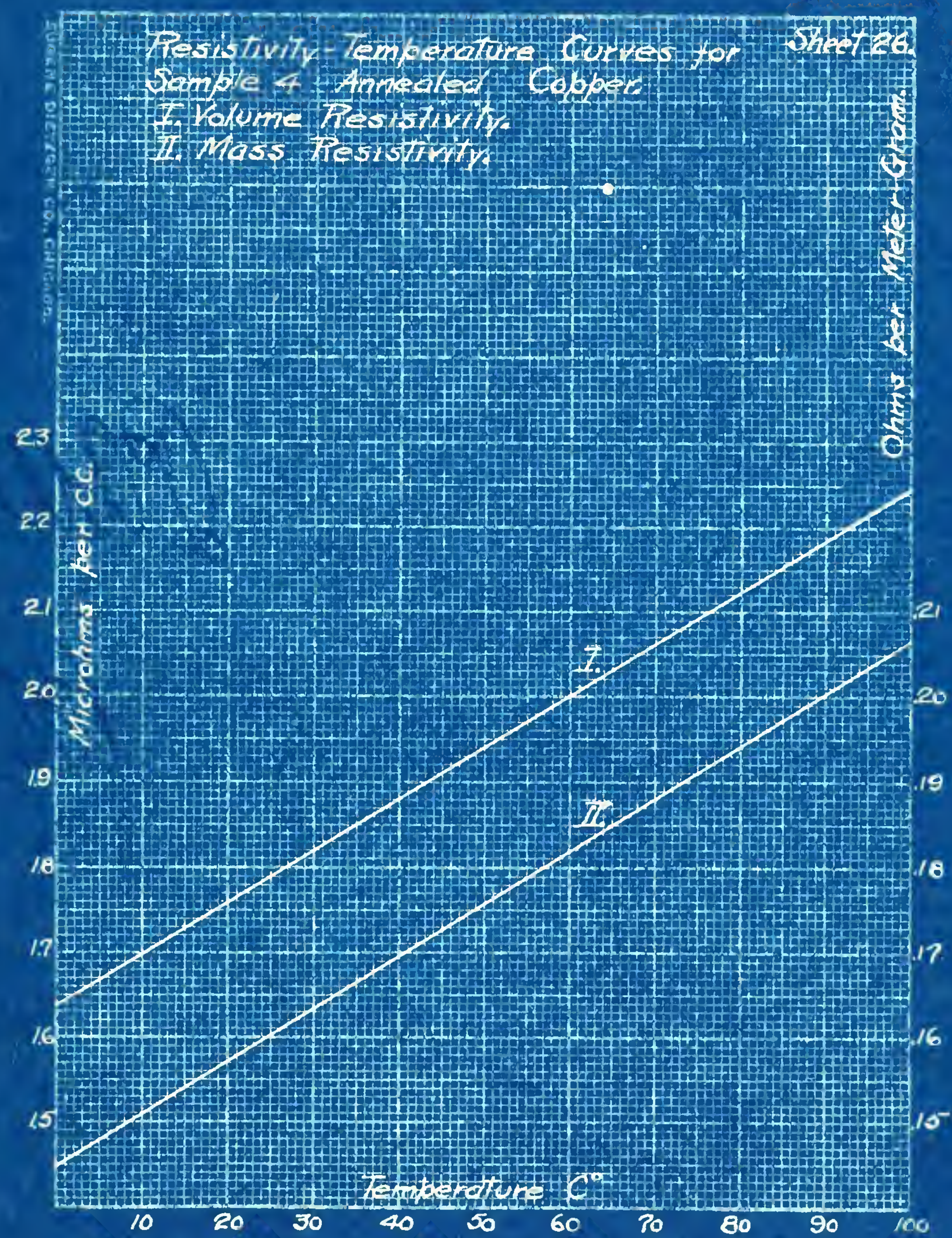

Resistivity-Temperature Curves for
Sample 1 Annealed Copper.
I. Volume Resistivity.
II. Mass Resistivity.
Sheet 22.
Microhms per c.c.
Ohms per meter Gram
I.
II.
Temperature C°
10 20 30 40 50 60 70 80 90
2.3 2.2 2.1 2.0 1.9 1.8 1.7 1.6 1.5
.21 .20 .19 .18 .17 .16 .15 .14

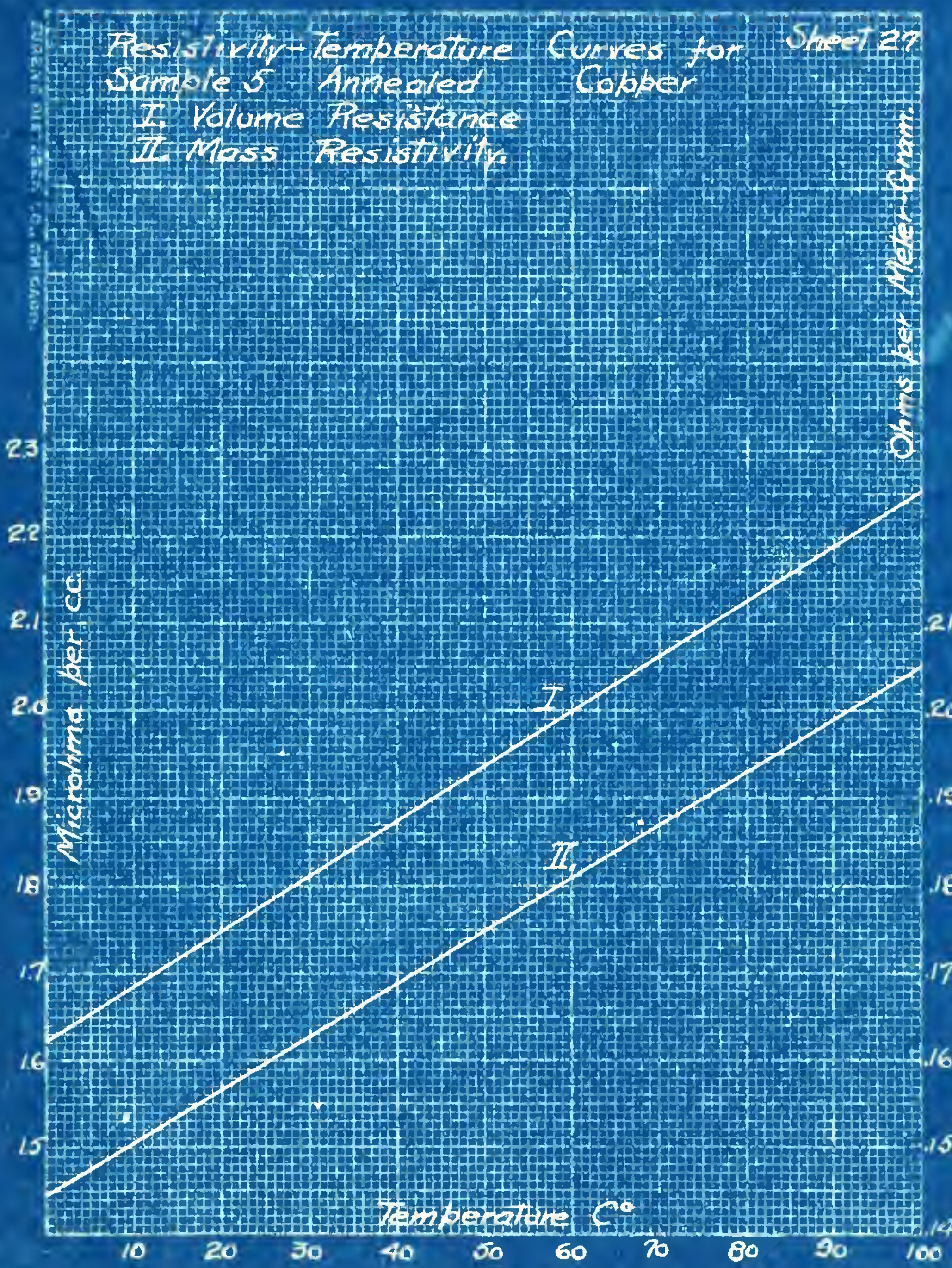

Resistivity-Temperature Curves for
Sample O Annealed Copper.
I. Volume Resistivity.
II. Mass Resistivity.
Sheet 23.
Microhms per c.c.
Ohms per Meter-Gram.
Temperature C°
I.
II.
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
.21
.20
.19
.18
.17
.16
.15
10
20
30
40
50
60
70
80
90
100

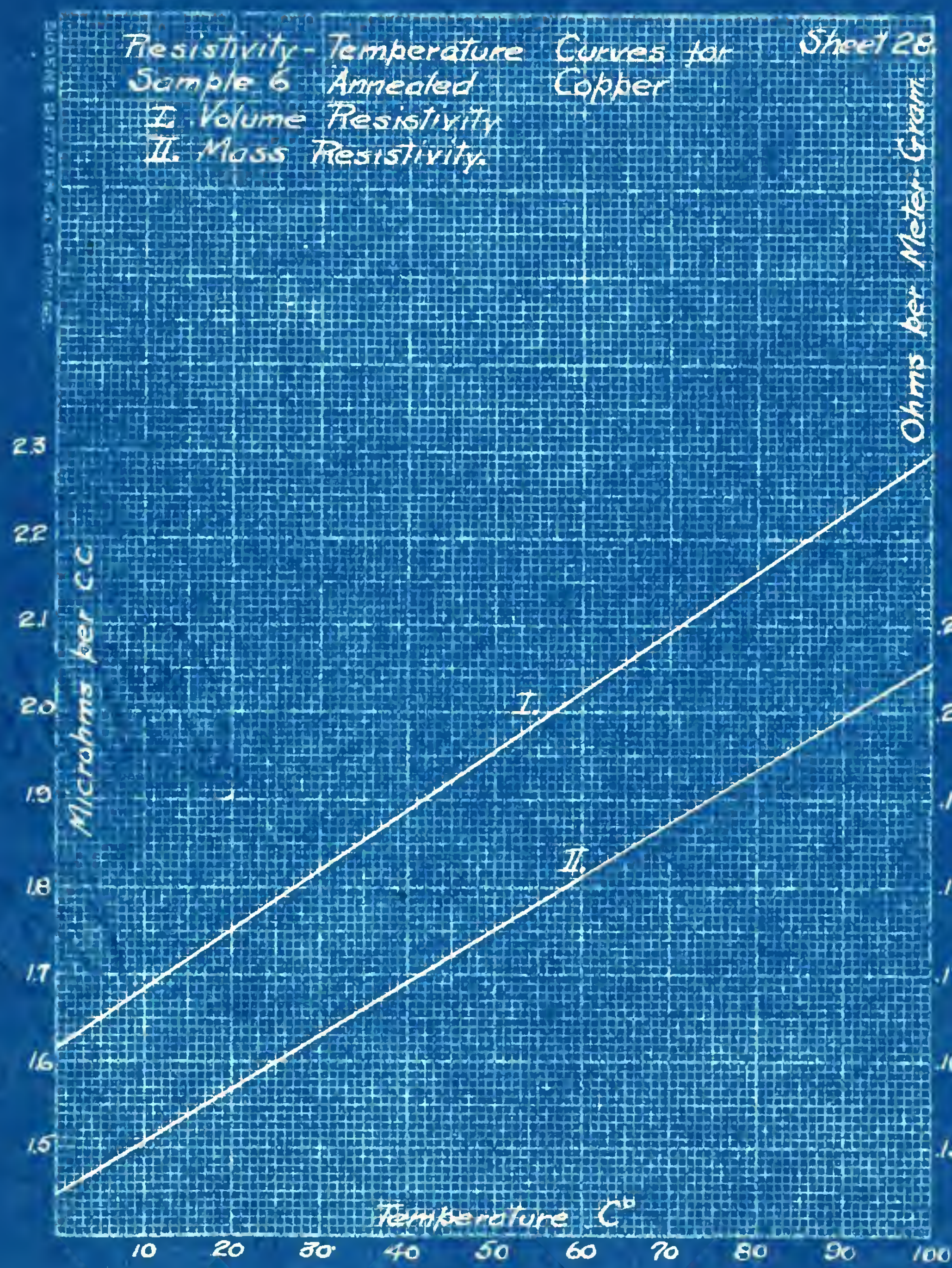


Resistivity-Temperature Curves for
Sample 10 Annealed Copper.
I. Volume Resistivity.
II. Mass Resistivity.
Sheet 24.
Microhms per c.c.
Ohms per Meter-Gram
Temperature C°
I.
II.
23
22
21
20
19
18
17
16
15
14
.21
.20
.19
.18
.17
.16
.15
10
20
30
40
50
60
70
80
90
100
EUGENE DIETZGEN CO., CHICAGO.

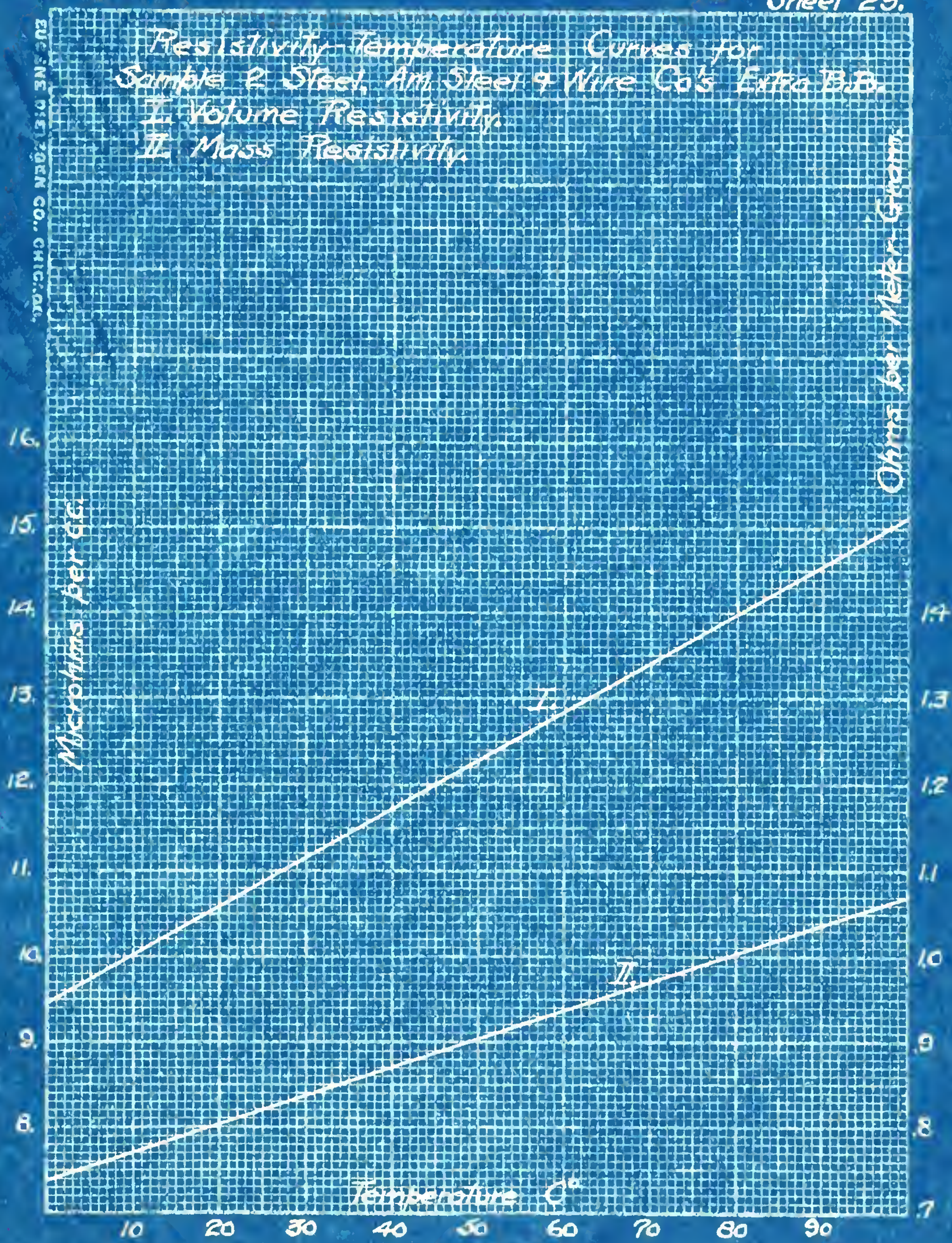

Resistivity-Temperature Curves for Sheet Bar.
Sample 3 Annealed Copper.
I. Volume Resistivity.
II. Mass Resistivity.
Microhms per cc
Ohms per Meter Gram
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
.21
.20
.19
.18
.17
.16
.15
I.
II.
Temperature C°
10
20
30
40
50
60
70
80
90
100


Resistivity-Temperature Curves for
Sample 4 Annealed Copper.
I. Volume Resistivity.
II. Mass Resistivity.
Sheet 26.
Microhms per C.C.
Ohms per Meter-Gram.
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
.21
.20
.19
.18
.17
.16
.15
I.
II.
Temperature C°
10 20 30 40 50 60 70 80 90 100


Resistivity-Temperature Curves for
Sample 5 Annealed Copper
I. Volume Resistance
II. Mass Resistivity.
Sheet 27
Microhms per c.c.
Ohms per Meter-Gram.
Temperature C°
I.
II.
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
.21
.20
.19
.18
.17
.16
.15
.14
10
20
30
40
50
60
70
80
90
100

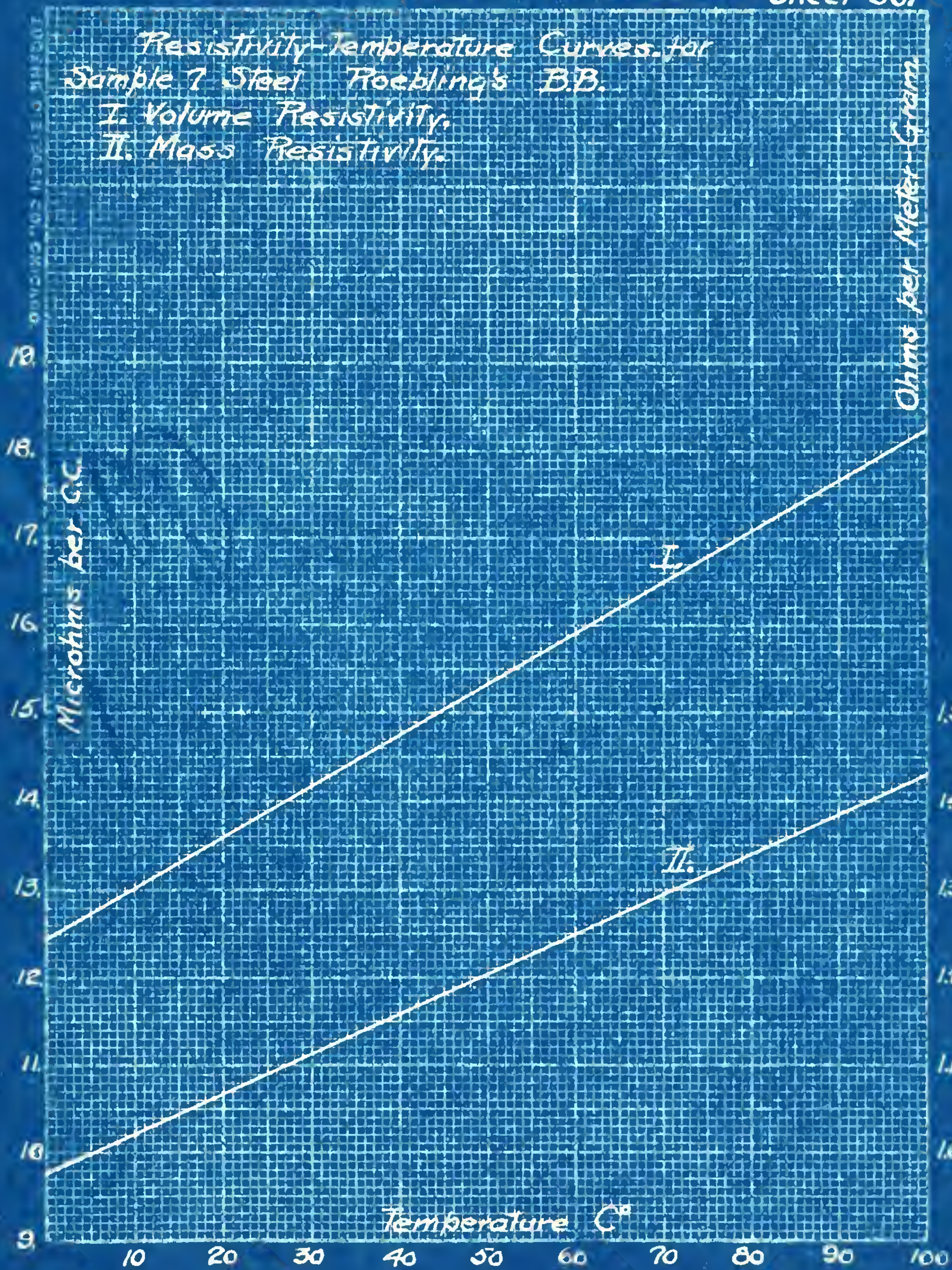

Resistivity - Temperature Curves for
Sample 6 Annealed Copper
I. Volume Resistivity
II. Mass Resistivity.
Sheet 28.
Microhms per C.C.
Ohms per Meter-Gram
Temperature C°
I.
II.
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
.21
.20
.19
.18
.17
.16
.15
10
20
30
40
50
60
70
80
90
100

Sheet 29.

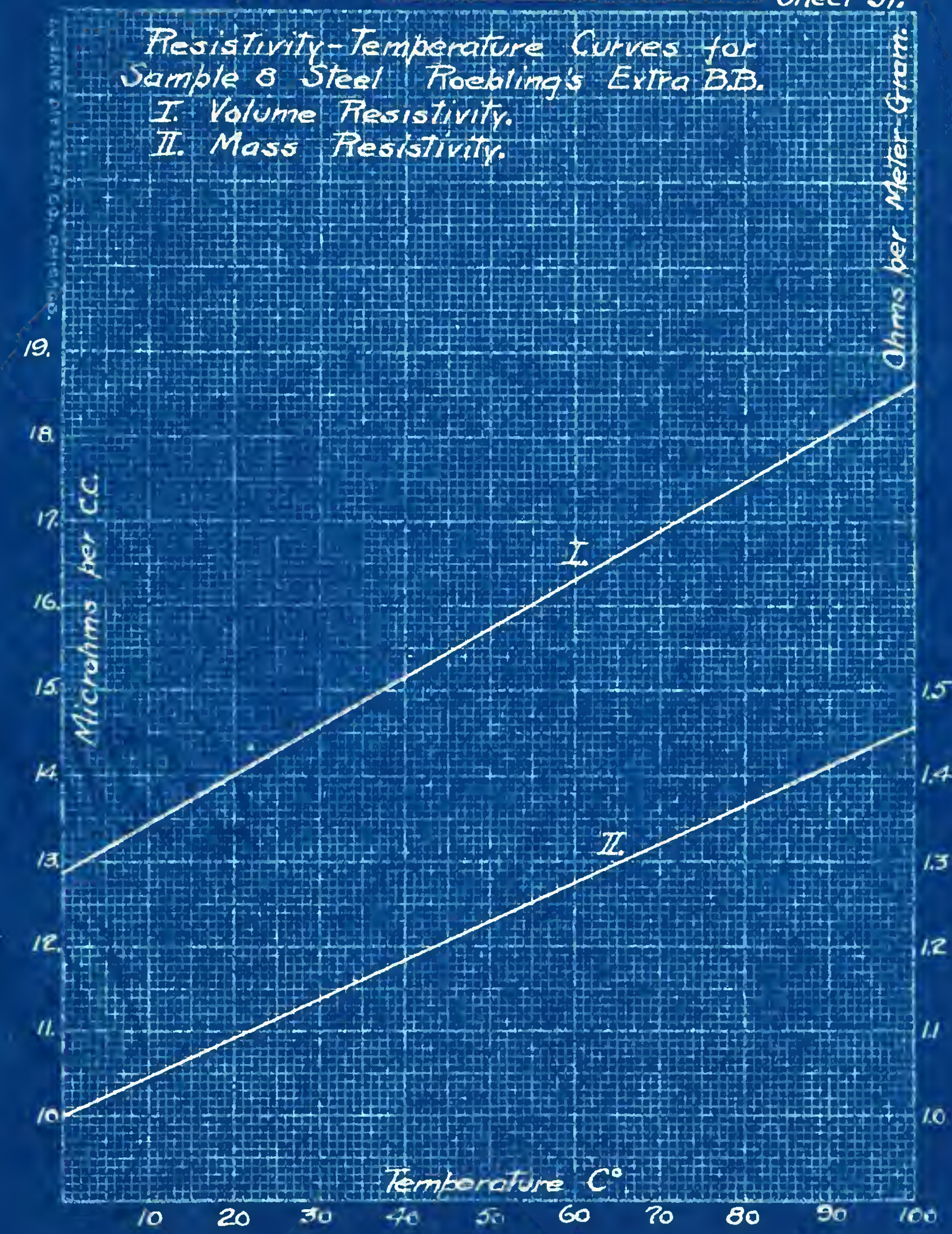


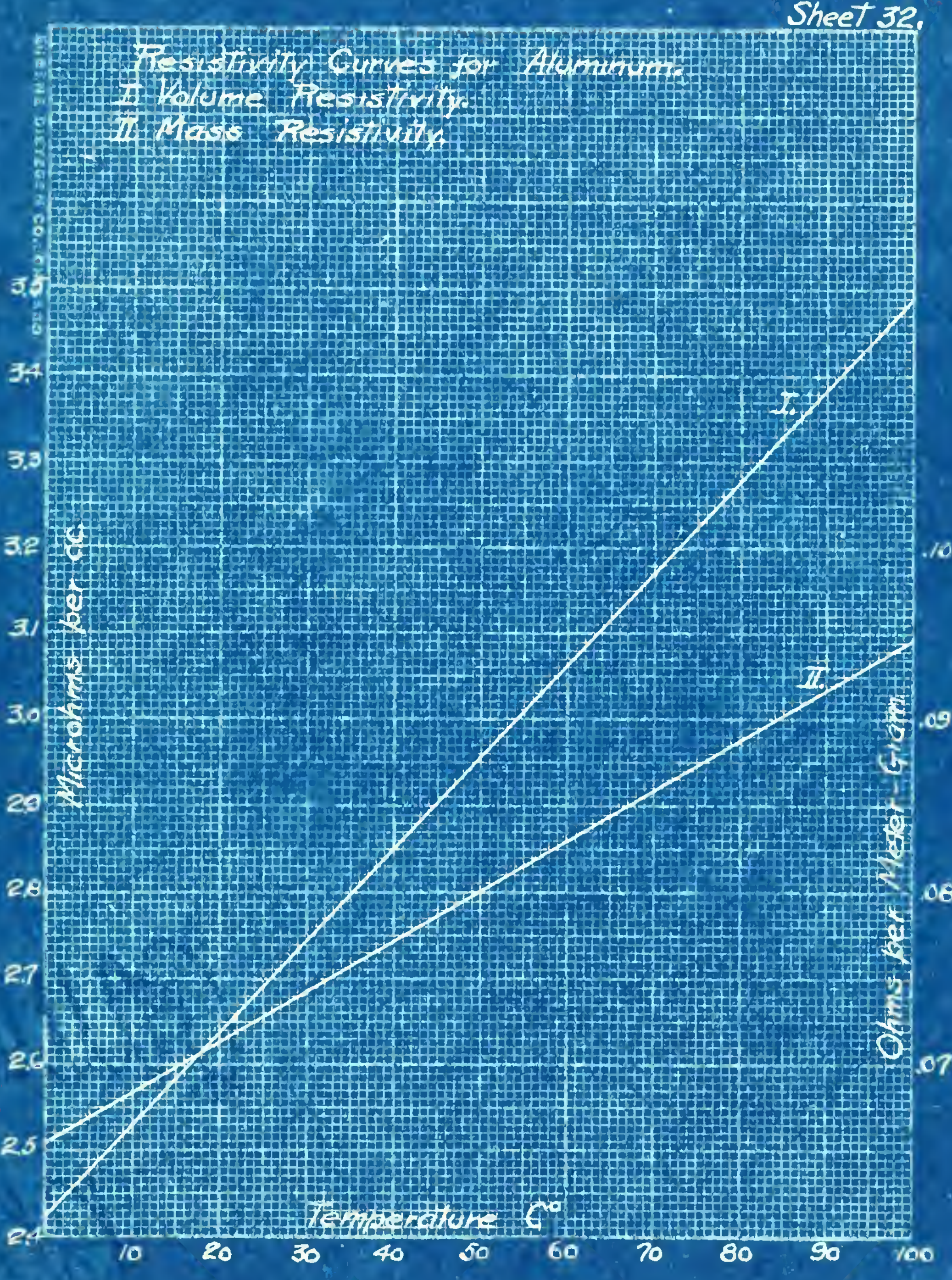
Resistivity-Temperature Curves for
Sample 2 Steel, Am. Steel & Wire Co's Extra B.B.
I. Volume Resistivity.
II. Mass Resistivity.
Microhms per c.c.
Ohms per Meter-Gram
Temperature C°
I.
II.
16.
15.
14.
13.
12.
11.
10.
9.
8.
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
10
20
30
40
50
60
70
80
90

Sheet 30.


Resistivity-Temperature Curves for
Sample 7 Steel Roebling's B.B.
I. Volume Resistivity.
II. Mass Resistivity.
Microhms per C.C.
Ohms per Meter-Gram
Temperature C°
I.
II.
9
10
11
12
13
14
15
16
17
18
19
1.0
1.1
1.2
1.3
1.4
1.5
10
20
30
40
50
60
70
80
90
100

Sheet 31.


Resistivity-Temperature Curves for
Sample 8 Steel Roebling's Extra B.B.
I. Volume Resistivity.
II. Mass Resistivity.
Microhms per C.C.
Ohms per Meter-Gram.
I.
II.
Temperature C°.
19.
18.
17.
16.
15.
14.
13.
12.
11.
10.
1.5
1.4
1.3
1.2
1.1
1.0
10
20
30
40
50
60
70
80
90
100


Sheet 32.
Resistivity Curves for Aluminum.
I Volume Resistivity.
II Mass Resistivity.
I.
II.
Microhms per cc.
Ohms per Meter Gram.
Temperature C°
2.4
2.5
2.6
2.7
2.8
2.9
3.0
3.1
3.2
3.3
3.4
3.5
.07
.08
.09
.10
10
20
30
40
50
60
70
80
90
100